DARWIN CHARLES

GEOLOGICAL OBSERVATIONS ON SOUTH AMERICA

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Содержание

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CRITICAL INTRODUCTION

Of the remarkable "trilogy" constituted by Darwin's writings which deal with the geology of the "Beagle," the member which has perhaps attracted least attention, up to the present time is that which treats of the geology of South America. The actual writing of this book appears to have occupied Darwin a shorter period than either of the other volumes of the series; his diary records that the work was accomplished within ten months, namely, between July 1844 and April 1845; but the book was not actually issued till late in the year following, the preface bearing the date "September 1846." Altogether, as Darwin informs us in his "Autobiography," the geological books "consumed four and a half years' steady work," most of the remainder of the ten years that elapsed between the return of the "Beagle," and the completion of his geological books being, it is sad to relate, "lost through illness!"

Concerning the "Geological Observations on South America," Darwin wrote to his friend Lyell, as follows: – "My volume

will be about 240 pages, dreadfully dull, yet much condensed. I think whenever you have time to look through it, you will think the collection of facts on the elevation of the land and on the formation of terraces pretty good."

"Much condensed" is the verdict that everyone must endorse, on rising from the perusal of this remarkable book; but by no means "dull." The three and a half years from April 1832 to September 1835, were spent by Darwin in South America, and were devoted to continuous scientific work; the problems he dealt with were either purely geological or those which constitute the borderland between the geological and biological sciences. It is impossible to read the journal which he kept during this time without being impressed by the conviction that it contains all the germs of thought which afterwards developed into the "Origin of Species." But it is equally evident that after his return to England, biological speculations gradually began to exercise a more exclusive sway over Darwin's mind, and tended to dispossess geology, which during the actual period of the voyage certainly engrossed most of his time and attention. The wonderful series of observations made during those three and a half years in South America could scarcely be done justice to, in the 240 pages devoted to their exposition. That he executed the work of preparing the book on South America in somewhat the manner of a task, is shown by many references in his letters. Writing to Sir Joseph Hooker in 1845, he says, "I hope this next summer to finish my South American Geology, then to get out a

little Zoology, and HURRAH FOR MY SPECIES WORK!"

It would seem that the feeling of disappointment, which Darwin so often experienced in comparing a book when completed, with the observations and speculations which had inspired it, was more keenly felt in the case of his volume on South America than any other. To one friend he writes, "I have of late been slaving extra hard, to the great discomfiture of wretched digestive organs, at South America, and thank all the fates, I have done three-fourths of it. Writing plain English grows with me more and more difficult, and never attainable. As for your pretending that you will read anything so dull as my pure geological descriptions, lay not such a flattering unction on my soul, for it is incredible." To another friend he writes, "You do not know what you threaten when you propose to read it – it is purely geological. I said to my brother, 'You will of course read it,' and his answer was, 'Upon my life, I would sooner even buy it.'"

In spite of these disparaging remarks, however, we are strongly inclined to believe that this book, despised by its author, and neglected by his contemporaries, will in the end be admitted to be one of Darwin's chief titles to fame. It is, perhaps, an unfortunate circumstance that the great success which he attained in biology by the publication of the "Origin of Species" has, to some extent, overshadowed the fact that Darwin's claims as a geologist, are of the very highest order. It is not too much to say that, had Darwin not been a geologist, the "Origin of

Species" could never have been written by him. But apart from those geological questions, which have an important bearing on biological thought and speculation, such as the proofs of imperfection in the geological record, the relations of the later tertiary faunas to the recent ones in the same areas, and the apparent intermingling of types belonging to distant geological epochs, when we study the palaeontology of remote districts, – there are other purely geological problems, upon which the contributions made by Darwin are of the very highest value. I believe that the verdict of the historians of science will be that if Darwin had not taken a foremost place among the biologists of this century, his position as a geologist would have been an almost equally commanding one.

But in the case of Darwin's principal geological work – that relating to the origin of the crystalline schists, – geologists were not at the time prepared to receive his revolutionary teachings. The influence of powerful authority was long exercised, indeed, to stifle his teaching, and only now, when this unfortunate opposition has disappeared, is the true nature and importance of Darwin's purely geological work beginning to be recognised.

The two first chapters of the "Geological Observations on South America," deal with the proofs which exist of great, but frequently interrupted, movements of elevation during very recent geological times. In connection with this subject, Darwin's particular attention was directed to the relations between the great earthquakes of South America – of some of which he

had impressive experience – and the permanent changes of elevation which were taking place. He was much struck by the rapidity with which the evidence of such great earth movements is frequently obliterated; and especially with the remarkable way in which the action of rain-water, percolating through deposits on the earth's surface, removes all traces of shells and other calcareous organisms. It was these considerations which were the parents of the generalisation that a palaeontological record can only be preserved during those periods in which long-continued slow subsidence is going on. This in turn, led to the still wider and more suggestive conclusion that the geological record as a whole is, and never can be more than, a series of more or less isolated fragments. The recognition of this important fact constitutes the keystone to any theory of evolution which seeks to find a basis in the actual study of the types of life that have formerly inhabited our globe.

In his third chapter, Darwin gives a number of interesting facts, collected during his visits to the plains and valleys of Chili, which bear on the question of the origin of saliferous deposits – the accumulation of salt, gypsum, and nitrate of soda. This is a problem that has excited much discussion among geologists, and which, in spite of many valuable observations, still remains to a great extent very obscure. Among the important considerations insisted upon by Darwin is that relating to the absence of marine shells in beds associated with such deposits. He justly argues that if the strata were formed in shallow waters, and then exposed

by upheaval to subaerial action, all shells and other calcareous organisms would be removed by solution.

Following Lyell's method, Darwin proceeds from the study of deposits now being accumulated on the earth's surface, to those which have been formed during the more recent periods of the geological history.

His account of the great Pampean formation, with its wonderful mammalian remains – Mastodon, Toxodon, Scelidotherium, Macrauchenia, Megatherium, Megalonyx, Mylodon, and Glyptodon – this full of interest. His discovery of the remains of a true Equus afforded a remarkable confirmation of the fact-already made out in North America – that species of horse had existed and become extinct in the New World, before their introduction by the Spaniards in the sixteenth century. Fully perceiving the importance of the microscope in studying the nature and origin of such deposits as those of the Pampas, Darwin submitted many of his specimens both to Dr. Carpenter in this country, and to Professor Ehrenberg in Berlin. Many very important notes on the microscopic organisms contained in the formation will be found scattered through the chapter.

Darwin's study of the older tertiary formations, with their abundant shells, and their relics of vegetable life buried under great sheets of basalt, led him to consider carefully the question of climate during these earlier periods. In opposition to prevalent views on this subject, Darwin points out that his observations are opposed to the conclusion that a higher temperature prevailed

universally over the globe during early geological periods. He argues that "the causes which gave to the older tertiary productions of the quite temperate zones of Europe a tropical character, WERE OF A LOCAL CHARACTER AND DID NOT AFFECT THE WHOLE GLOBE." In this, as in many similar instances, we see the beneficial influence of extensive travel in freeing Darwin's mind from prevailing prejudices. It was this widening of experience which rendered him so especially qualified to deal with the great problem of the origin of species, and in doing so to emancipate himself from ideas which were received with unquestioning faith by geologists whose studies had been circumscribed within the limits of Western Europe.

In the Cordilleras of Northern and Central Chili, Darwin, when studying still older formations, clearly recognised that they contain an admixture of the forms of life, which in Europe are distinctive of the Cretaceous and Jurassic periods respectively. He was thus led to conclude that the classification of geological periods, which fairly well expresses the facts that had been discovered in the areas where the science was first studied, is no longer capable of being applied when we come to the study of widely distant regions. This important conclusion led up to the further generalisation that each great geological period has exhibited a geographical distribution of the forms of animal and vegetable life, comparable to that which prevails in the existing fauna and flora. To those who are familiar with the extent to which the doctrine of universal

formations has affected geological thought and speculation, both long before and since the time that Darwin wrote, the importance of this new standpoint to which he was able to attain will be sufficiently apparent. Like the idea of the extreme imperfection of the Geological Record, the doctrine of LOCAL geological formations is found permeating and moulding all the palaeontological reasonings of his great work.

In one of Darwin's letters, written while he was in South America, there is a passage we have already quoted, in which he expresses his inability to decide between the rival claims upon his attention of "the old crystalline group of rocks," and "the softer fossiliferous beds" respectively. The sixth chapter of the work before us, entitled "Plutonic and Metamorphic Rocks – Cleavage and Foliation," contains a brief summary of a series of observations and reasonings upon these crystalline rocks, which are, we believe, calculated to effect a revolution in geological science, and – though their value and importance have long been overlooked – are likely to entitle Darwin in the future to a position among geologists, scarcely, if at all, inferior to that which he already occupies among biologists.

Darwin's studies of the great rock-masses of the Andes convinced him of the close relations between the granitic or Plutonic rocks, and those which were undoubtedly poured forth as lavas. Upon his return, he set to work, with the aid of Professor Miller, to make a careful study of the minerals composing the granites and those which occur in the lavas,

and he was able to show that in all essential respects they are identical. He was further able to prove that there is a complete gradation between the highly crystalline or granitic rock-masses, and those containing more or less glassy matter between their crystals, which constitute ordinary lavas. The importance of this conclusion will be realised when we remember that it was then the common creed of geologists – and still continues to be so on the Continent – that all highly crystalline rocks are of great geological antiquity, and that the igneous ejections which have taken place since the beginning of the tertiary periods differ essentially, in their composition, their structure, and their mode of occurrence, from those which have made their appearance at earlier periods of the world's history.

Very completely have the conclusions of Darwin upon these subjects been justified by recent researches. In England, the United States, and Italy, examples of the gradual passage of rocks of truly granitic structure into ordinary lavas have been described, and the reality of the transition has been demonstrated by the most careful studies with the microscope. Recent researches carried on in South America by Professor Stelzner, have also shown the existence of a class of highly crystalline rocks – the "Andengranites" – which combine in themselves many of the characteristics which were once thought to be distinctive of the so-called Plutonic and volcanic rocks. No one familiar with recent geological literature – even in Germany and France, where the old views concerning the distinction

of igneous products of different ages have been most stoutly maintained – can fail to recognise the fact that the principles contended for by Darwin bid fair at no distant period to win universal acceptance among geologists all over the globe.

Still more important are the conclusions at which Darwin arrived with respect to the origin of the schists and gneisses which cover so large an area in South America.

Carefully noting, by the aid of his compass and clinometer, at every point which he visited, the direction and amount of inclination of the parallel divisions in these rocks, he was led to a very important generalisation – namely, that over very wide areas the direction (strike) of the planes of cleavage in slates, and of foliation in schists and gneisses, remained constant, though the amount of their inclination (dip) often varied within wide limits. Further than this it appeared that there was always a close correspondence between the strike of the cleavage and foliation and the direction of the great axes along which elevation had taken place in the district.

In Tierra del Fuego, Darwin found striking evidence that the cleavage intersecting great masses of slate-rocks was quite independent of their original stratification, and could often, indeed, be seen cutting across it at right angles. He was also able to verify Sedgwick's observation that, in some slates, glossy surfaces on the planes of cleavage arise from the development of new minerals, chlorite, epidote or mica, and that in this way a complete graduation from slates to true schists may be traced.

Darwin further showed that in highly schistose rocks, the folia bend around and encircle any foreign bodies in the mass, and that in some cases they exhibit the most tortuous forms and complicated puckerings. He clearly saw that in all cases the forces by which these striking phenomena must have been produced were persistent over wide areas, and were connected with the great movements by which the rocks had been upheaved and folded.

That the distinct folia of quartz, feldspar, mica, and other minerals composing the metamorphic schists could not have been separately deposited as sediment was strongly insisted upon by Darwin; and in doing so he opposed the view generally prevalent among geologists at that time. He was thus driven to the conclusion that foliation, like cleavage, is not an original, but a superinduced structure in rock-masses, and that it is the result of re-crystallisation, under the controlling influence of great pressure, of the materials of which the rock was composed.

In studying the lavas of Ascension, as we have already seen, Darwin was led to recognise the circumstance that, when igneous rocks are subjected to great differential movements during the period of their consolidation, they acquire a foliated structure, closely analogous to that of the crystalline schists. Like his predecessor in this field of inquiry, Mr. Poulett Scrope, Charles Darwin seems to have been greatly impressed by these facts, and he argued from them that the rocks exhibiting the foliated structure must have been in a state of plasticity, like that of a

cooling mass of lava. At that time the suggestive experiments of Tresca, Daubree, and others, showing that solid masses under the influence of enormous pressure become actually plastic, had not been published. Had Darwin been aware of these facts he would have seen that it was not necessary to assume a state of imperfect solidity in rock-masses in order to account for their having yielded to pressure and tension, and, in doing so, acquiring the new characters which distinguish the crystalline schists.

The views put forward by Darwin on the origin of the crystalline schists found an able advocate in Mr. Daniel Sharpe, who in 1852 and 1854 published two papers, dealing with the geology of the Scottish Highlands and of the Alps respectively, in which he showed that the principles arrived at by Darwin when studying the South American rocks afford a complete explanation of the structure of the two districts in question.

But, on the other hand, the conclusions of Darwin and Sharpe were met with the strongest opposition by Sir Roderick Murchison and Dr. A. Geikie, who in 1861 read a paper before the Geological Society "On the Coincidence between Stratification and Foliation in the Crystalline Rocks of the Scottish Highlands," in which they insisted that their observations in Scotland tended to entirely disprove the conclusions of Darwin that foliation in rocks is a secondary structure, and entirely independent of the original stratification of the rock-masses.

Now it is a most significant circumstance that, no sooner did the officers of the Geological Survey commence the careful and detailed study of the Scottish Highlands than they found themselves compelled to make a formal retraction of the views which had been put forward by Murchison and Geikie in opposition to the conclusions of Darwin. The officers of the Geological Survey have completely abandoned the view that the foliation of the Highland rocks has been determined by their original stratification, and admit that the structure is the result of the profound movements to which the rocks have been subjected. The same conclusions have recently been supported by observations made in many different districts – among which we may especially refer to those of Dr. H. Reusch in Norway, and those of Dr. J. Lehmann in Saxony. At the present time the arguments so clearly stated by Darwin in the work before us, have, after enduring opposition or neglect for a whole generation, begun to "triumph all along the line," and we may look forward confidently to the near future, when his claim to be regarded as one of the greatest of geological discoverers shall be fully vindicated.

JOHN W. JUDD.

CHAPTER I. ON THE ELEVATION OF THE EASTERN COAST OF SOUTH AMERICA

Upraised shells of La Plata.

Bahia Blanca, Sand-dunes and Pumice-pebbles.

Step-formed plains of Patagonia, with upraised Shells.

Terrace-bounded Valley of Santa Cruz, formerly a Sea-strait.

Upraised shells of Tierra del Fuego.

Length and breadth of the elevated area.

Equability of the movements, as shown by the similar heights of the plains.

Slowness of the elevatory process.

Mode of formation of the step-formed plains.

Summary.

Great Shingle Formation of Patagonia; its extent, origin, and distribution.

Formation of sea-cliffs.

In the following Volume, which treats of the geology of South America, and almost exclusively of the parts southward of the Tropic of Capricorn, I have arranged the chapters according to the age of the deposits, occasionally departing from this order, for the sake of geographical simplicity.

The elevation of the land within the recent period, and the

modifications of its surface through the action of the sea (to which subjects I paid particular attention) will be first discussed; I will then pass on to the tertiary deposits, and afterwards to the older rocks. Only those districts and sections will be described in detail which appear to me to deserve some particular attention; and I will, at the end of each chapter, give a summary of the results. We will commence with the proofs of the upheaval of the eastern coast of the continent, from the Rio Plata southward; and, in the Second Chapter, follow up the same subject along the shores of Chile and Peru.

On the northern bank of the great estuary of the Rio Plata, near Maldonado, I found at the head of a lake, sometimes brackish but generally containing fresh water, a bed of muddy clay, six feet in thickness, with numerous shells of species still existing in the Plata, namely, the Azara labiata, d'Orbigny, fragments of Mytilus eduliformis, d'Orbigny, Paludestrina Isabellei, d'Orbigny, and the Solen Caribaeus, Lam., which last was embedded vertically in the position in which it had lived. These shells lie at the height of only two feet above the lake, nor would they have been worth mentioning, except in connection with analogous facts.

At Monte Video, I noticed near the town, and along the base of the mount, beds of a living Mytilus, raised some feet above the surface of the Plata: in a similar bed, at a height from thirteen to sixteen feet, M. Isabelle collected eight species, which, according to M. d'Orbigny, now live at the mouth of the estuary. ("Voyage

dans l'Amerique Merid.: Part. Geolog." page 21.) At Colonia del Sacramiento, further westward, I observed at the height of about fifteen feet above the river, there of quite fresh water, a small bed of the same Mytilus, which lives in brackish water at Monte Video. Near the mouth of Uruguay, and for at least thirty-five miles northward, there are at intervals large sandy tracts, extending several miles from the banks of the river, but not raised much above its level, abounding with small bivalves, which occur in such numbers that at the Agraciado they are sifted and burnt for lime. Those which I examined near the A. S. Juan were much worn: they consisted of Mactra Isabellei, d'Orbigny, mingled with few of Venus sinuosa, Lam., both inhabiting, as I am informed by M. d'Orbigny, brackish water at the mouth of the Plata, nearly or quite as salt as the open sea. The loose sand, in which these shells are packed, is heaped into low, straight, long lines of dunes, like those left by the sea at the head of many bays. M. d'Orbigny has described an analogous phenomenon on a greater scale, near San Pedro on the river Parana, where he found widely extended beds and hillocks of sand, with vast numbers of the Azara labiata, at the height of nearly 100 feet (English) above the surface of that river. (Ibid page 43.) The Azara inhabits brackish water, and is not known to be found nearer to San Pedro than Buenos Ayres, distant above a hundred miles in a straight line. Nearer Buenos Ayres, on the road from that place to San Isidro, there are extensive beds, as I am informed by Sir Woodbine Parish, of the Azara labiata, lying at about forty

feet above the level of the river, and distant between two and three miles from it. ("Buenos Ayres" etc. by Sir Woodbine Parish page 168.) These shells are always found on the highest banks in the district: they are embedded in a stratified earthy mass, precisely like that of the great Pampean deposit hereafter to be described. In one collection of these shells, there were some valves of the Venus sinuosa, Lam., the same species found with the Mactra on the banks of the Uruguay. South of Buenos Ayres, near Ensenada, there are other beds of the Azara, some of which seem to have been embedded in yellowish, calcareous, semi-crystalline matter; and Sir W. Parish has given me from the banks of the Arroyo del Tristan, situated in this same neighbourhood, at the distance of about a league from the Plata, a specimen of a pale- reddish, calcereo-argillaceous stone (precisely like parts of the Pampean deposit the importance of which fact will be referred to in a succeeding chapter), abounding with shells of an Azara, much worn, but which in general form and appearance closely resemble, and are probably identical with, the A. labiata. Besides these shells, cellular, highly crystalline rock, formed of the casts of small bivalves, is found near Ensenada; and likewise beds of sea-shells, which from their appearance appear to have lain on the surface. Sir W. Parish has given me some of these shells, and M. d'Orbigny pronounces them to be: —

1. Buccinanops globulosum, d'Orbigny.
2. Olivancillaria auricularia, d'Orbigny.
3. Venus flexuosa, Lam.

4. Cytheraea (imperfect).
5. Mactra Isabellei, d'Orbigny.
6. Ostrea pulchella, d'Orbigny.

Besides these, Sir W. Parish procured ("Buenos Ayres" etc. by Sir W. Parish page 168.) (as named by Mr. G.B. Sowerby) the following shells: —

7. Voluta colocynthis.
8. Voluta angulata.
9. Buccinum (not spec.?).

All these species (with, perhaps, the exception of the last) are recent, and live on the South American coast. These shell-beds extend from one league to six leagues from the Plata, and must lie many feet above its level. I heard, also, of beds of shells on the Somborombon, and on the Rio Salado, at which latter place, as M. d'Orbigny informs me, the Mactra Isabellei and Venus sinuosa are found.

During the elevation of the Provinces of La Plata, the waters of the ancient estuary have but little affected (with the exception of the sand- hills on the banks of the Parana and Uruguay) the outline of the land. M. Parchappe, however, has described groups of sand dunes scattered over the wide extent of the Pampas southward of Buenos Ayres (D'Orbigny "Voyage Geolog." page 44.), which M. d'Orbigny attributes with much probability to the action of the sea, before the plains were raised above its level. (Before proceeding to the districts southward of La Plata, it may be worth while just to state, that there is some evidence that the

coast of Brazil has participated in a small amount of elevation. Mr. Burchell informs me, that he collected at Santos (latitude 24 degrees S.) oyster-shells, apparently recent, some miles from the shore, and quite above the tidal action. Westward of Rio de Janeiro, Captain Elliot is asserted (see Harlan "Med. and Phys. Res." page 35 and Dr. Meigs in "Transactions of the American Philosophical Society"), to have found human bones, encrusted with sea-shells, between fifteen and twenty feet above the level of the sea. Between Rio de Janeiro and Cape Frio I crossed sandy tracts abounding with sea-shells, at a distance of a league from the coast; but whether these tracts have been formed by upheaval, or through the mere accumulation of drift sand, I am not prepared to assert. At Bahia (latitude 13 degrees S.), in some parts near the coast, there are traces of sea-action at the height of about twenty feet above its present level; there are also, in many parts, remnants of beds of sandstone and conglomerate with numerous recent shells, raised a little above the sea-level. I may add, that at the head of Bahia Bay there is a formation, about forty feet in thickness, containing tertiary shells apparently of fresh-water origin, now washed by the sea and encrusted with Balini; this appears to indicate a small amount of subsidence subsequent to its deposition. At Pernambuco (latitude 8 degrees S.), in the alluvial or tertiary cliffs, surrounding the low land on which the city stands, I looked in vain for organic remains, or other evidence of changes in level.)

SOUTHWARD OF THE PLATA.

The coast as far as Bahia Blanca (in latitude 39 degrees S.) is formed either of a horizontal range of cliffs, or of immense accumulations of sand-dunes. Within Bahia Blanca, a small piece of tableland, about twenty feet above high-water mark, called Punta Alta, is formed of strata of cemented gravel and of red earthy mud, abounding with shells (with others lying loose on the surface), and the bones of extinct mammifers. These shells, twenty in number, together with a Balanus and two corals, are all recent species, still inhabiting the neighbouring seas. They will be enumerated in the Fourth Chapter, when describing the Pampean formation; five of them are identical with the upraised ones from near Buenos Ayres. The northern shore of Bahia Blanca is, in main part, formed of immense sand-dunes, resting on gravel with recent shells, and ranging in lines parallel to the shore. These ranges are separated from each other by flat spaces, composed of stiff impure red clay, in which, at the distance of about two miles from the coast, I found by digging a few minute fragments of sea-shells. The sand-dunes extend several miles inland, and stand on a plain, which slopes up to a height of between one hundred and two hundred feet. Numerous, small, well-rounded pebbles of pumice lie scattered both on the plain and sand-hillocks: at Monte Hermoso, on the flat summit of a cliff, I found many of them at a height of 120 feet (angular measurement) above the level of the sea. These pumice pebbles, no doubt, were originally brought down from the Cordillera by the rivers which cross the continent, in the same way as the river Negro anciently

brought down, and still brings down, pumice, and as the river Chupat brings down scoriae: when once delivered at the mouth of a river, they would naturally have travelled along the coasts, and been cast up during the elevation of the land, at different heights. The origin of the argillaceous flats, which separate the parallel ranges of sand-dunes, seems due to the tides here having a tendency (as I believe they have on most shoal, protected coasts) to throw up a bar parallel to the shore, and at some distance from it; this bar gradually becomes larger, affording a base for the accumulation of sand- dunes, and the shallow space within then becomes silted up with mud. The repetition of this process, without any elevation of the land, would form a level plain traversed by parallel lines of sand-hillocks; during a slow elevation of the land, the hillocks would rest on a gently inclined surface, like that on the northern shore of Bahia Blanca. I did not observe any shells in this neighbourhood at a greater height than twenty feet; and therefore the age of the sea-drifted pebbles of pumice, now standing at the height of 120 feet, must remain uncertain.

The main plain surrounding Bahia Blanca I estimated at from two hundred to three hundred feet; it insensibly rises towards the distant Sierra Ventana. There are in this neighbourhood some other and lower plains, but they do not abut one at the foot of the other, in the manner hereafter to be described, so characteristic of Patagonia. The plain on which the settlement stands is crossed by many low sand-dunes, abounding with the

minute shells of the Paludestrina australis, d'Orbigny, which now lives in the bay. This low plain is bounded to the south, at the Cabeza del Buey, by the cliff-formed margin of a wide plain of the Pampean formation, which I estimated at sixty feet in height. On the summit of this cliff there is a range of high sand-dunes extending several miles in an east and west line.

Southward of Bahia Blanca, the river Colorado flows between two plains, apparently from thirty to forty feet in height. Of these plains, the southern one slopes up to the foot of the great sandstone plateau of the Rio Negro; and the northern one against an escarpment of the Pampean deposit; so that the Colorado flows in a valley fifty miles in width, between the upper escarpments. I state this, because on the low plain at the foot of the northern escarpment, I crossed an immense accumulation of high sand-dunes, estimated by the Gauchos at no less than eight miles in breadth. These dunes range westward from the coast, which is twenty miles distant, to far inland, in lines parallel to the valley; they are separated from each other by argillaceous flats, precisely like those on the northern shore of Bahia Blanca. At present there is no source whence this immense accumulation of sand could proceed; but if, as I believe, the upper escarpments once formed the shores of an estuary, in that case the sandstone formation of the river Negro would have afforded an inexhaustible supply of sand, which would naturally have accumulated on the northern shore, as on every part of the coast open to the south winds between Bahia Blanca and Buenos

Ayres.

At San Blas (40 degrees 40' S.) a little south of the mouth of the Colorado, M. d'Orbigny found fourteen species of existing shells (six of them identical with those from Bahia Blanca), embedded in their natural positions. ("Voyage" etc. page 54.) From the zone of depth which these shells are known to inhabit, they must have been uplifted thirty-two feet. He also found, at from fifteen to twenty feet above this bed, the remains of an ancient beach.

Ten miles southward, but 120 miles to the west, at Port S. Antonio, the Officers employed on the Survey assured me that they saw many old sea- shells strewed on the surface of the ground, similar to those found on other parts of the coast of Patagonia. At San Josef, ninety miles south in nearly the same longitude, I found, above the gravel, which caps an old tertiary formation, an irregular bed and hillock of sand, several feet in thickness, abounding with shells of Patella deaurita, Mytilus Magellanicus, the latter retaining much of its colour; Fusus Magellanicus (and a variety of the same), and a large Balanus (probably B. Tulipa), all now found on this coast: I estimated this bed at from eighty to one hundred feet above the level of the sea. To the westward of this bay, there is a plain estimated at between two hundred and three hundred feet in height: this plain seems, from many measurements, to be a continuation of the sandstone platform of the river Negro. The next place southward, where I landed, was at Port Desire, 340 miles distant; but from

the intermediate districts I received, through the kindness of the Officers of the Survey, especially from Lieutenant Stokes and Mr. King, many specimens and sketches, quite sufficient to show the general uniformity of the whole line of coast. I may here state, that the whole of Patagonia consists of a tertiary formation, resting on and sometimes surrounding hills of porphyry and quartz: the surface is worn into many wide valleys and into level step-formed plains, rising one above another, all capped by irregular beds of gravel, chiefly composed of porphyritic rocks. This gravel formation will be separately described at the end of the chapter.

My object in giving the following measurements of the plains, as taken by the Officers of the Survey, is, as will hereafter be seen, to show the remarkable equability of the recent elevatory movements. Round the southern parts of Nuevo Gulf, as far as the River Chupat (seventy miles southward of San Josef), there appear to be several plains, of which the best defined are here represented.

(In the following Diagrams: 1. Baseline is Level of sea. 2. Scale is 1/20 of inch to 100 feet vertical. 3. Height is shown in feet thus: An. M. always stands for angular or trigonometrical measurement. Ba. M. always stands for barometrical measurement. Est. always stands for estimation by the Officers of the Survey.

DIAGRAM 1. SECTION OF STEP-FORMED PLAINS SOUTH OF NUEVO GULF.

From East (sea level) to West (high):

Terrace 1. 80 Est.

Terrace 2. 200-220 An. M.

Terrace 3. 350 An. M.)

The upper plain is here well defined (called Table Hills); its edge forms a cliff or line of escarpment many miles in length, projecting over a lower plain. The lowest plain corresponds with that at San Josef with the recent shells on its surface. Between this lowest and the uppermost plain, there is probably more than one step-formed terrace: several measurements show the existence of the intermediate one of the height given in Diagram 1.

(DIAGRAM 2. SECTION OF PLAINS IN THE BAY OF ST. GEORGE.

From East (sea level) to West (high):

Terrace 1. 250 An. M.

Terrace 2. 330 An. M.

Terrace 3. 580 An. M.

Terraces 4, 5 and 6 not measured.

Terrace 7. 1,200 Est.)

Near the north headland of the great Bay of St. George (100 miles south of the Chupat), two well-marked plains of 250 and 330 feet were measured: these are said to sweep round a great part of the Bay. At its south headland, 120 miles distant from the north headland, the 250 feet plain was again measured. In the middle of the bay, a higher plain was found at two neighbouring places (Tilli Roads and C. Marques) to be 580 feet in height.

Above this plain, towards the interior, Mr. Stokes informs me that there were several other step-formed plains, the highest of which was estimated at 1,200 feet, and was seen ranging at apparently the same height for 150 miles northward. All these plains have been worn into great valleys and much denuded. The section in Diagram 3 is illustrative of the general structure of the great Bay of St. George. At the south headland of the Bay of St. George (near C. Three Points) the 250 plain is very extensive.

(DIAGRAM 3. SECTION OF PLAINS AT PORT DESIRE.

From East (sea level) to West (high):

Terrace 1. 100 Est.

Terrace 2. 245-255 Ba. M. Shells on surface.

Terrace 3. 330 Ba. M. Shells on surface.

Terrace 4. Not measured.)

At Port Desire (forty miles southward) I made several measurements with the barometer of a plain, which extends along the north side of the port and along the open coast, and which varies from 245 to 255 feet in height: this plain abuts against the foot of a higher plain of 330 feet, which extends also far northward along the coast, and likewise into the interior. In the distance a higher inland platform was seen, of which I do not know the height. In three separate places, I observed the cliff of the 245-255 feet plain, fringed by a terrace or narrow plain estimated at about one hundred feet in height. These plains are represented in the section Diagram 3.

In many places, even at the distance of three and four miles from the coast, I found on the gravel-capped surface of the 245-255 feet, and of the 330 feet plain, shells of Mytilus Magellanicus, M. edulis, Patella deaurita, and another Patella, too much worn to be identified, but apparently similar to one found abundantly adhering to the leaves of the kelp. These species are the commonest now living on this coast. The shells all appeared very old; the blue of the mussels was much faded; and only traces of colour could be perceived in the Patellas, of which the outer surfaces were scaling off. They lay scattered on the smooth surface of the gravel, but abounded most in certain patches, especially at the heads of the smaller valleys: they generally contained sand in their insides; and I presume that they have been washed by alluvial action out of thin sandy layers, traces of which may sometimes be seen covering the gravel. The several plains have very level surfaces; but all are scooped out by numerous broad, winding, flat-bottomed valleys, in which, judging from the bushes, streams never flow. These remarks on the state of the shells, and on the nature of the plains, apply to the following cases, so need not be repeated.

(DIAGRAM 4. SECTION OF PLAINS AT PORT S. JULIAN.

From East (sea level) to West (high):

Terrace 1. Shells on surface. 90 Est.

Terrace 2. 430 An. M.

Terrace 3. 560 An. M.

Terrace 4. 950 An. M.)

Southward of Port Desire, the plains have been greatly denuded, with only small pieces of tableland marking their former extension. But opposite Bird Island, two considerable step-formed plains were measured, and found respectively to be 350 and 590 feet in height. This latter plain extends along the coast close to Port St. Julian (110 miles south of Port Desire); see Diagram 4.

The lowest plain was estimated at ninety feet: it is remarkable from the usual gravel-bed being deeply worn into hollows, which are filled up with, as well as the general surface covered by, sandy and reddish earthy matter: in one of the hollows thus filled up, the skeleton of the Macrauchenia Patachonica, as will hereafter be described, was embedded. On the surface and in the upper parts of this earthy mass, there were numerous shells of Mytilus Magellanicus and M. edulis, Patella deaurita, and fragments of other species. This plain is tolerably level, but not extensive; it forms a promontory seven or eight miles long, and three or four wide. The upper plains in Diagram 4 were measured by the Officers of the Survey; they were all capped by thick beds of gravel, and were all more or less denuded; the 950 plain consists merely of separate, truncated, gravel-capped hills, two of which, by measurement, were found to differ only three feet. The 430 feet plain extends, apparently with hardly a break, to near the northern entrance of the Rio Santa Cruz (fifty miles to the south); but it was there found to be only 330 feet in height.

(DIAGRAM 5. SECTION OF PLAINS AT THE MOUTH OF THE RIO SANTA CRUZ.

From East (sea level) to West (high):

Terrace 1. (sloping) 355 Ba. M. Shells on surface. 463 Ba. M.

Terrace 2. 710 An. M.

Terrace 3. 840 An. M.)

On the southern side of the mouth of the Santa Cruz we have Diagram 5, which I am able to give with more detail than in the foregoing cases.

The plain marked 355 feet (as ascertained by the barometer and by angular measurement) is a continuation of the above-mentioned 330 feet plain: it extends in a N.W. direction along the southern shores of the estuary. It is capped by gravel, which in most parts is covered by a thin bed of sandy earth, and is scooped out by many flat-bottomed valleys. It appears to the eye quite level, but in proceeding in a S.S.W. course, towards an escarpment distant about six miles, and likewise ranging across the country in a N.W. line, it was found to rise at first insensibly, and then for the last half-mile, sensibly, close up to the base of the escarpment: at this point it was 463 feet in height, showing a rise of 108 feet in the six miles. On this 355-463 feet plain, I found several shells of Mytilus Magellanicus and of a Mytilus, which Mr. Sowerby informs me is yet unnamed, though well-known as recent on this coast; Patella deaurita; Fusus, I believe, Magellanicus, but the specimen has been lost; and at the distance of four miles from the coast, at the height of about

four hundred feet, there were fragments of the same Patella and of a Voluta (apparently V. ancilla) partially embedded in the superficial sandy earth. All these shells had the same ancient appearance with those from the foregoing localities. As the tides along this part of the coast rise at the Syzygal period forty feet, and therefore form a well-marked beach-line, I particularly looked out for ridges in crossing this plain, which, as we have seen, rises 108 feet in about six miles, but I could not see any traces of such. The next highest plain is 710 feet above the sea; it is very narrow, but level, and is capped with gravel; it abuts to the foot of the 840 feet plain. This summit-plain extends as far as the eye can range, both inland along the southern side of the valley of the Santa Cruz, and southward along the Atlantic.

THE VALLEY OF THE R. SANTA CRUZ.

This valley runs in an east and west direction to the Cordillera, a distance of about one hundred and sixty miles. It cuts through the great Patagonian tertiary formation, including, in the upper half of the valley, immense streams of basaltic lava, which as well as the softer beds, are capped by gravel; and this gravel, high up the river, is associated with a vast boulder formation. (I have described this formation in a paper in the "Geological Transactions" volume 6 page 415.) In ascending the valley, the plain which at the mouth on the southern side is 355 feet high, is seen to trend towards the corresponding plain on the northern side, so that their escarpments appear like the shores of a former estuary, larger than the existing one: the escarpments, also, of

the 840 feet summit-plain (with a corresponding northern one, which is met with some way up the valley), appear like the shores of a still larger estuary. Farther up the valley, the sides are bounded throughout its entire length by level, gravel-capped terraces, rising above each other in steps. The width between the upper escarpments is on an average between seven and ten miles; in one spot, however, where cutting through the basaltic lava, it was only one mile and a half. Between the escarpments of the second highest terrace the average width is about four or five miles. The bottom of the valley, at the distance of 110 miles from its mouth, begins sensibly to expand, and soon forms a considerable plain, 440 feet above the level of the sea, through which the river flows in a gut from twenty to forty feet in depth. I here found, at a point 140 miles from the Atlantic, and seventy miles from the nearest creek of the Pacific, at the height of 410 feet, a very old and worn shell of Patella deaurita. Lower down the valley, 105 miles from the Atlantic (longitude 71 degrees W.), and at an elevation of about 300 feet, I also found, in the bed of the river, two much worn and broken shells of the Voluta ancilla, still retaining traces of their colours; and one of the Patella deaurita. It appeared that these shells had been washed from the banks into the river; considering the distance from the sea, the desert and absolutely unfrequented character of the country, and the very ancient appearance of the shells (exactly like those found on the plains nearer the coast), there is, I think, no cause to suspect that they could have been brought here by

Indians.

The plain at the head of the valley is tolerably level, but water-worn, and with many sand-dunes on it like those on a sea-coast. At the highest point to which we ascended, it was sixteen miles wide in a north and south line; and forty-five miles in length in an east and west line. It is bordered by the escarpments, one above the other, of two plains, which diverge as they approach the Cordillera, and consequently resemble, at two levels, the shores of great bays facing the mountains; and these mountains are breached in front of the lower plain by a remarkable gap. The valley, therefore, of the Santa Cruz consists of a straight broad cut, about ninety miles in length, bordered by gravel-capped terraces and plains, the escarpments of which at both ends diverge or expand, one over the other, after the manner of the shores of great bays. Bearing in mind this peculiar form of the land – the sand-dunes on the plain at the head of the valley – the gap in the Cordillera, in front of it – the presence in two places of very ancient shells of existing species – and lastly, the circumstance of the 355-453 feet plain, with the numerous marine remains on its surface, sweeping from the Atlantic coast, far up the valley, I think we must admit, that within the recent period, the course of the Santa Cruz formed a sea-strait intersecting the continent. At this period, the southern part of South America consisted of an archipelago of islands 360 miles in a north and south line. We shall presently see, that two other straits also, since closed, then cut through Tierra del Fuego;

I may add, that one of them must at that time have expanded at the foot of the Cordillera into a great bay (now Otway Water) like that which formerly covered the 440 feet plain at the head of the Santa Cruz.

(DIAGRAM 6. NORTH AND SOUTH SECTION ACROSS THE TERRACES BOUNDING THE VALLEY OF THE RIVER SANTA CRUZ, HIGH UP ITS COURSE.

The height of each terrace, above the level of the river (furthest to nearest to the river) in feet:

A, north and south: 1,122

B, north and south: 869

C, north and south: 639

D, north: not measured. D, north? (suggest south): 185

E: 20

Bed of River.

Vertical scale 1/20 of inch to 100 feet; but terrace E, being only twenty feet above the river, has necessarily been raised. The horizontal distances much contracted; the distance from the edge of A North to A South being on an average from seven to ten miles.) I have said that the valley in its whole course is bordered by gravel- capped plains. The section (Diagram 6), supposed to be drawn in a north and south line across the valley, can scarcely be considered as more than illustrative; for during our hurried ascent it was impossible to measure all the plains at any one place. At a point nearly midway between the Cordillera and the Atlantic, I found the plain (A north) 1,122 feet above the river;

all the lower plains on this side were here united into one great broken cliff: at a point sixteen miles lower down the stream, I found by measurement and estimation that B (north) was 869 above the river: very near to where A (north) was measured, C (north) was 639 above the same level: the terrace D (north) was nowhere measured: the lowest E (north) was in many places about twenty feet above the river. These plains or terraces were best developed where the valley was widest; the whole five, like gigantic steps, occurred together only at a few points. The lower terraces are less continuous than the higher ones, and appear to be entirely lost in the upper third of the valley. Terrace C (south), however was traced continuously for a great distance. The terrace B (north), at a point fifty- five miles from the mouth of the river, was four miles in width; higher up the valley this terrace (or at least the second highest one, for I could not always trace it continuously) was about eight miles wide. This second plain was generally wider than the lower ones – as indeed follows from the valley from A (north) to A (south) being generally nearly double the width of from B (north) to B (south). Low down the valley, the summit-plain A (south) is continuous with the 840 feet plain on the coast, but it is soon lost or unites with the escarpment of B (south). The corresponding plain A (north), on the north side of the valley, appears to range continuously from the Cordillera to the head of the present estuary of the Santa Cruz, where it trends northward towards Port St. Julian. Near the Cordillera the summit-plain on both sides of the valley is between 3,200 and

3,300 feet in height; at 100 miles from the Atlantic, it is 1,416 feet, and on the coast 840 feet, all above the sea-beach; so that in a distance of 100 miles the plain rises 576 feet, and much more rapidly near to the Cordillera. The lower terraces B and C also appear to rise as they run up the valley; thus D (north), measured at two points twenty-four miles apart, was found to have risen 185 feet. From several reasons I suspect, that this gradual inclination of the plains up the valley, has been chiefly caused by the elevation of the continent in mass, having been the greater the nearer to the Cordillera.

All the terraces are capped with well-rounded gravel, which rests either on the denuded and sometimes furrowed surface of the soft tertiary deposits, or on the basaltic lava. The difference in height between some of the lower steps or terraces seems to be entirely owing to a difference in the thickness of the capping gravel. Furrows and inequalities in the gravel, where such occur, are filled up and smoothed over with sandy earth. The pebbles, especially on the higher plains, are often whitewashed, and even cemented together by a white aluminous substance, and I occasionally found this to be the case with the gravel on the terrace D. I could not perceive any trace of a similar deposition on the pebbles now thrown up by the river, and therefore I do not think that terrace D was river-formed. As the terrace E generally stands about twenty feet above the bed of the river, my first impression was to doubt whether even this lowest one could have been so formed; but it should always be borne in mind, that the

horizontal upheaval of a district, by increasing the total descent of the streams, will always tend to increase, first near the sea-coast and then further and further up the valley, their corroding and deepening powers: so that an alluvial plain, formed almost on a level with a stream, will, after an elevation of this kind, in time be cut through, and left standing at a height never again to be reached by the water. With respect to the three upper terraces of the Santa Cruz, I think there can be no doubt, that they were modelled by the sea, when the valley was occupied by a strait, in the same manner (hereafter to be discussed) as the greater step-formed, shell- strewed plains along the coast of Patagonia.

To return to the shores of the Atlantic: the 840 feet plain, at the mouth of the Santa Cruz, is seen extending horizontally far to the south; and I am informed by the Officers of the Survey, that bending round the head of Coy Inlet (sixty-five miles southward), it trends inland. Outliers of apparently the same height are seen forty miles farther south, inland of the river Gallegos; and a plain comes down to Cape Gregory (thirty-five miles southward), in the Strait of Magellan, which was estimated at between eight hundred and one thousand feet in height, and which, rising towards the interior, is capped by the boulder formation. South of the Strait of Magellan, there are large outlying masses of apparently the same great tableland, extending at intervals along the eastern coast of Tierra del Fuego: at two places here, 110 miles a part, this plain was found to be 950 and 970 feet in height.

From Coy Inlet, where the high summit-plain trends inland, a

plain estimated at 350 feet in height, extends for forty miles to the river Gallegos. From this point to the Strait of Magellan, and on each side of that Strait, the country has been much denuded and is less level. It consists chiefly of the boulder formation, which rises to a height of between one hundred and fifty and two hundred and fifty feet, and is often capped by beds of gravel. At N.S. Gracia, on the north side of the Inner Narrows of the Strait of Magellan, I found on the summit of a cliff, 160 feet in height, shells of existing Patellae and Mytili, scattered on the surface and partially embedded in earth. On the eastern coast, also, of Tierra del Fuego, in latitude 53 degrees 20' south, I found many Mytili on some level land, estimated at 200 feet in height. Anterior to the elevation attested by these shells, it is evident by the present form of the land, and by the distribution of the great erratic boulders on the surface, that two sea-channels connected the Strait of Magellan both with Sebastian Bay and with Otway Water. ("Geological Transactions" volume 6 page 419.)

CONCLUDING REMARKS ON THE RECENT ELEVATION OF THE SOUTH-EASTERN COASTS OF AMERICA, AND ON THE ACTION OF THE SEA ON THE LAND.

Upraised shells of species, still existing as the commonest kinds in the adjoining sea, occur, as we have seen, at heights of between a few feet and 410 feet, at intervals from latitude 33 degrees 40' to 53 degrees 20' south. This is a distance of 1,180 geographical miles – about equal from London to the North

Cape of Sweden. As the boulder formation extends with nearly the same height 150 miles south of 53 degrees 20', the most southern point where I landed and found upraised shells; and as the level Pampas ranges many hundred miles northward of the point, where M. d'Orbigny found at the height of 100 feet beds of the Azara, the space in a north and south line, which has been uplifted within the recent period, must have been much above the 1,180 miles. By the term "recent," I refer only to that period within which the now living mollusca were called into existence; for it will be seen in the Fourth Chapter, that both at Bahia Blanca and P. S. Julian, the mammiferous quadrupeds which co-existed with these shells belong to extinct species. I have said that the upraised shells were found only at intervals on this line of coast, but this in all probability may be attributed to my not having landed at the intermediate points; for wherever I did land, with the exception of the river Negro, shells were found: moreover, the shells are strewed on plains or terraces, which, as we shall immediately see, extend for great distances with a uniform height. I ascended the higher plains only in a few places, owing to the distance at which their escarpments generally range from the coast, so that I am far from knowing that 410 feet is the maximum of elevation of these upraised remains. The shells are those now most abundant in a living state in the adjoining sea. (Captain King "Voyages of 'Adventure' and 'Beagle'" volume 1 pages 6 and 133.) All of them have an ancient appearance; but some, especially the mussels, although lying fully exposed

to the weather, retain to a considerable extent their colours: this circumstance appears at first surprising, but it is now known that the colouring principle of the Mytilus is so enduring, that it is preserved when the shell itself is completely disintegrated. (See Mr. Lyell "Proofs of a Gradual Rising in Sweden" in the "Philosophical Transactions" 1835 page 1. See also Mr. Smith of Jordan Hill in the "Edinburgh New Philosophical Journal" volume 25 page 393.) Most of the shells are broken; I nowhere found two valves united; the fragments are not rounded, at least in none of the specimens which I brought home.

With respect to the breadth of the upraised area in an east and west line, we know from the shells found at the Inner Narrows of the Strait of Magellan, that the entire width of the plain, although there very narrow, has been elevated. It is probable that in this southernmost part of the continent, the movement has extended under the sea far eastward; for at the Falkland Islands, though I could not find any shells, the bones of whales have been noticed by several competent observers, lying on the land at a considerable distance from the sea, and at the height of some hundred feet above it. ("Voyages of the 'Adventure' and 'Beagle'" volume 2 page 227. And Bougainville's "Voyage" tome 1 page 112.) Moreover, we know that in Tierra del Fuego the boulder formation has been uplifted within the recent period, and a similar formation occurs on the north-western shores (Byron Sound) of these islands. (I owe this fact to the kindness of Captain Sulivan, R.N., a highly competent

observer. I mention it more especially, as in my Paper (page 427) on the Boulder Formation, I have, after having examined the northern and middle parts of the eastern island, said that the formation was here wholly absent.) The distance from this point to the Cordillera of Tierra del Fuego, is 360 miles, which we may take as the probable width of the recently upraised area. In the latitude of the R. Santa Cruz, we know from the shells found at the mouth and head, and in the middle of the valley, that the entire width (about 160 miles) of the surface eastward of the Cordillera has been upraised. From the slope of the plains, as shown by the course of the rivers, for several degrees northward of the Santa Cruz, it is probable that the elevation attested by the shells on the coast has likewise extended to the Cordillera. When, however, we look as far northward as the provinces of La Plata, this conclusion would be very hazardous; not only is the distance from Maldonado (where I found upraised shells) to the Cordillera great, namely, 760 miles, but at the head of the estuary of the Plata, a N.N.E. and S.S.W. range of tertiary volcanic rocks has been observed (This volcanic formation will be described in Chapter IV. It is not improbable that the height of the upraised shells at the head of the estuary of the Plata, being greater than at Bahia Blanca or at San Blas, may be owing to the upheaval of these latter places having been connected with the distant line of the Cordillera, whilst that of the provinces of La Plata was in connection with the adjoining tertiary volcanic axis.), which may well indicate an axis of elevation quite distinct from that of the

Andes. Moreover, in the centre of the Pampas in the chain of Cordova, severe earthquakes have been felt (See Sir W. Parish's work on "La Plata" page 242. For a notice of an earthquake which drained a lake near Cordova, see also Temple's "Travels in Peru." Sir W. Parish informs me, that a town between Salta and Tucuman (north of Cordova) was formerly utterly overthrown by an earthquake.); whereas at Mendoza, at the eastern foot of the Cordillera, only gentle oscillations, transmitted from the shores of the Pacific, have ever been experienced. Hence the elevation of the Pampas may be due to several distinct axes of movement; and we cannot judge, from the upraised shells round the estuary of the Plata, of the breadth of the area uplifted within the recent period.

Not only has the above specified long range of coast been elevated within the recent period, but I think it may be safely inferred from the similarity in height of the gravel-capped plains at distant points, that there has been a remarkable degree of equability in the elevatory process. I may premise, that when I measured the plains, it was simply to ascertain the heights at which shells occurred; afterwards, comparing these measurements with some of those made during the Survey, I was struck with their uniformity, and accordingly tabulated all those which represented the summit-edges of plains. The extension of the 330 to 355 feet plain is very striking, being found over a space of 500 geographical miles in a north and south line. A table (Table 1) of the measurements is given below. The angular

measurements and all the estimations (in feet) are by the Officers of the Survey; the barometrical ones by myself: —

TABLE 1.

Gallegos River to Coy Inlet (partly angular partly estimation) 350

South Side of Santa Cruz (angular and barometric) 355

North Side of Santa Cruz (angular and barometric) 330

Bird Island, plain opposite to (angular) 350

Port Desire, plain extending far along coast (barometric) 330

St. George's Bay, north promontory (angular) 330

Table Land, south of New Bay (angular) 350

A plain, varying from 245 to 255 feet, seems to extend with much uniformity from Port Desire to the north of St. George's Bay, a distance of 170 miles; and some approximate measurements (in feet), also given in Table 2 below, indicate the much greater extension of 780 miles: —

TABLE 2.

Coy Inlet, south of (partly angular and partly estimation) 200 to 300

Port Desire (barometric) 245 to 255

C. Blanco (angular) 250

North Promontory of St. George's Bay (angular) 250

South of New Bay (angular) 200 to 220

North of S. Josef (estimation) 200 to 300

Plain of Rio Negro (angular) 200 to 220

Bahia Blanca (estimation) 200 to 300

The extension, moreover, of the 560 to 580, and of the 80 to 100 feet, plains is remarkable, though somewhat less obvious than in the former cases. Bearing in mind that I have not picked these measurements out of a series, but have used all those which represented the edges of plains, I think it scarcely possible that these coincidences in height should be accidental. We must therefore conclude that the action, whatever it may have been, by which these plains have been modelled into their present forms, has been singularly uniform.

These plains or great terraces, of which three and four often rise like steps one behind the other, are formed by the denudation of the old Patagonian tertiary beds, and by the deposition on their surfaces of a mass of well-rounded gravel, varying, near the coast, from ten to thirty-five feet in thickness, but increasing in thickness towards the interior. The gravel is often capped by a thin irregular bed of sandy earth. The plains slope up, though seldom sensibly to the eye, from the summit edge of one escarpment to the foot of the next highest one. Within a distance of 150 miles, between Santa Cruz to Port Desire, where the plains are particularly well developed, there are at least seven stages or steps, one above the other. On the three lower ones, namely, those of 100 feet, 250 feet, and 350 feet in height, existing littoral shells are abundantly strewed, either on the surface, or partially embedded in the superficial sandy earth. By whatever action these three lower plains have been modelled, so undoubtedly have all the higher ones, up to a height of 950 feet

at S. Julian, and of 1,200 feet (by estimation) along St. George's Bay. I think it will not be disputed, considering the presence of the upraised marine shells, that the sea has been the active power during stages of some kind in the elevatory process.

We will now briefly consider this subject: if we look at the existing coast-line, the evidence of the great denuding power of the sea is very distinct; for, from Cape St. Diego, in latitude 54 degrees 30' to the mouth of the Rio Negro, in latitude 31 degrees (a length of more than eight hundred miles), the shore is formed, with singularly few exceptions, of bold and naked cliffs: in many places the cliffs are high; thus, south of the Santa Cruz, they are between eight and nine hundred feet in height, with their horizontal strata abruptly cut off, showing the immense mass of matter which has been removed. Nearly this whole line of coast consists of a series of greater or lesser curves, the horns of which, and likewise certain straight projecting portions, are formed of hard rocks; hence the concave parts are evidently the effect and the measure of the denuding action on the softer strata. At the foot of all the cliffs, the sea shoals very gradually far outwards; and the bottom, for a space of some miles, everywhere consists of gravel. I carefully examined the bed of the sea off the Santa Cruz, and found that its inclination was exactly the same, both in amount and in its peculiar curvature, with that of the 355 feet plain at this same place. If, therefore, the coast, with the bed of the adjoining sea, were now suddenly elevated one or two hundred feet, an inland line of cliffs, that is an escarpment, would

be formed, with a gravel-capped plain at its foot gently sloping to the sea, and having an inclination like that of the existing 355 feet plain. From the denuding tendency of the sea, this newly formed plain would in time be eaten back into a cliff: and repetitions of this elevatory and denuding process would produce a series of gravel-capped sloping terraces, rising one above another, like those fronting the shores of Patagonia.

The chief difficulty (for there are other inconsiderable ones) on this view, is the fact, – as far as I can trust two continuous lines of soundings carefully taken between Santa Cruz and the Falkland Islands, and several scattered observations on this and other coasts, – that the pebbles at the bottom of the sea QUICKLY and REGULARLY decrease in size with the increasing depth and distance from the shore, whereas in the gravel on the sloping plains, no such decrease in size was perceptible.

Table 3 below gives the average result of many soundings off the Santa

Cruz: —

TABLE 3.

Under two miles from the shore, many of the pebbles were of large size, mingled with some small ones.

Column 1. Distance in miles from the shore.

Column 2. Depth in fathoms.

Column 3. Size of Pebbles.

1. 2. 3.

3 to 4 11 to 12 As large as walnuts; mingled in every case with some smaller ones.

6 to 7 17 to 19 As large as hazel-nuts.

10 to 11 23 to 25 From three- to four-tenths of an inch in diameter.

12 30 to 40 Two-tenths of an inch.

22 to 150 45 to 65 One-tenth of an inch, to the finest sand.

I particularly attended to the size of the pebbles on the 355 feet Santa Cruz plain, and I noticed that on the summit-edge of the present sea cliffs many were as large as half a man's head; and in crossing from these cliffs to the foot of the next highest escarpment, a distance of six miles, I could not observe any increase in their size. We shall presently see that the theory of a slow and almost insensible rise of the land, will explain all the facts connected with the gravel-capped terraces, better than the theory of sudden elevations of from one to two hundred feet.

M. d'Orbigny has argued, from the upraised shells at San Blas being embedded in the positions in which they lived, and from the valves of the Azara labiata high on the banks of the Parana being united and unrolled, that the elevation of Northern Patagonia and of La Plata must have been sudden; for he thinks, if it had been gradual, these shells would all have been rolled on successive beach-lines. But in PROTECTED bays, such as in that of Bahia Blanca, wherever the sea is accumulating extensive mud-banks, or where the winds quietly heap up sand-dunes, beds of shells might assuredly be preserved buried in the positions

in which they had lived, even whilst the land retained the same level; any, the smallest, amount of elevation would directly aid in their preservation. I saw a multitude of spots in Bahia Blanca where this might have been effected; and at Maldonado it almost certainly has been effected. In speaking of the elevation of the land having been slow, I do not wish to exclude the small starts which accompany earthquakes, as on the coast of Chile; and by such movements beds of shells might easily be uplifted, even in positions exposed to a heavy surf, without undergoing any attrition: for instance, in 1835, a rocky flat off the island of Santa Maria was at one blow upheaved above high-water mark, and was left covered with gaping and putrefying mussel-shells, still attached to the bed on which they had lived. If M. d'Orbigny had been aware of the many long parallel lines of sand-hillocks, with infinitely numerous shells of the Mactra and Venus, at a low level near the Uruguay; if he had seen at Bahia Blanca the immense sand-dunes, with water-worn pebbles of pumice, ranging in parallel lines, one behind the other, up a height of at least 120 feet; if he had seen the sand-dunes, with the countless Paludestrinas, on the low plain near the Fort at this place, and that long line on the edge of the cliff, sixty feet higher up; if he had crossed that long and great belt of parallel sand-dunes, eight miles in width, standing at the height of from forty to fifty feet above the Colorado, where sand could not now collect, – I cannot believe he would have thought that the elevation of this great district had been sudden. Certainly the sand-dunes

(especially when abounding with shells), which stand in ranges at so many different levels, must all have required long time for their accumulation; and hence I do not doubt that the last 100 feet of elevation of La Plata and Northern Patagonia has been exceedingly slow.

If we extend this conclusion to Central and Southern Patagonia, the inclination of the successively rising gravel-capped plains can be explained quite as well, as by the more obvious view already given of a few comparatively great and sudden elevations; in either case we must admit long periods of rest, during which the sea ate deeply into the land. Let us suppose the present coast to rise at a nearly equable, slow rate, yet sufficiently quick to prevent the waves quite removing each part as soon as brought up; in this case every portion of the present bed of the sea will successively form a beach-line, and from being exposed to a like action will be similarly affected. It cannot matter to what height the tides rise, even if to forty feet as at Santa Cruz, for they will act with equal force and in like manner on each successive line. Hence there is no difficulty in the fact of the 355 feet plain at Santa Cruz sloping up 108 feet to the foot of the next highest escarpment, and yet having no marks of any one particular beach-line on it; for the whole surface on this view has been a beach. I cannot pretend to follow out the precise action of the tidal-waves during a rise of the land, slow, yet sufficiently quick to prevent or check denudation: but if it be analogous to what takes place on protected parts

of the present coast, where gravel is now accumulating in large quantities, an inclined surface, thickly capped by well-rounded pebbles of about the same size, would be ultimately left. (On the eastern side of Chiloe, which island we shall see in the next chapter is now rising, I observed that all the beaches and extensive tidal-flats were formed of shingle.) On the gravel now accumulating, the waves, aided by the wind, sometimes throw up a thin covering of sand, together with the common coast-shells. Shells thus cast up by gales, would, during an elevatory period, never again be touched by the sea. Hence, on this view of a slow and gradual rising of the land, interrupted by periods of rest and denudation, we can understand the pebbles being of about the same size over the entire width of the step-like plains, – the occasional thin covering of sandy earth, – and the presence of broken, unrolled fragments of those shells, which now live exclusively near the coast.

SUMMARY OF RESULTS.

It may be concluded that the coast on this side of the continent, for a space of at least 1,180 miles, has been elevated to a height of 100 feet in La Plata, and of 400 feet in Southern Patagonia, within the period of existing shells, but not of existing mammifers. That in La Plata the elevation has been very slowly effected: that in Patagonia the movement may have been by considerable starts, but much more probably slow and quiet. In either case, there have been long intervening periods of comparative rest, during which the sea corroded deeply, as it is

still corroding, into the land. (I say COMPARATIVE and not ABSOLUTE rest, because the sea acts, as we have seen, with great denuding power on this whole line of coast; and therefore, during an elevation of the land, if excessively slow (and of course during a subsidence of the land), it is quite possible that lines of cliff might be formed.) That the periods of denudation and elevation were contemporaneous and equable over great spaces of coast, as shown by the equable heights of the plains; that there have been at least eight periods of denudation, and that the land, up to a height of from 950 to 1,200 feet, has been similarly modelled and affected: that the area elevated, in the southernmost part of the continent, extended in breadth to the Cordillera, and probably seaward to the Falkland Islands; that northward, in La Plata, the breadth is unknown, there having been probably more than one axis of elevation; and finally, that, anterior to the elevation attested by these upraised shells, the land was divided by a Strait where the River Santa Cruz now flows, and that further southward there were other sea-straits, since closed. I may add, that at Santa Cruz, in latitude 50 degrees S., the plains have been uplifted at least 1,400 feet, since the period when gigantic boulders were transported between sixty and seventy miles from their parent rock, on floating icebergs.

Lastly, considering the great upward movements which this long line of coast has undergone, and the proximity of its southern half to the volcanic axis of the Cordillera, it is highly remarkable that in the many fine sections exposed in

the Pampean, Patagonian tertiary, and Boulder formations, I nowhere observed the smallest fault or abrupt curvature in the strata.

GRAVEL FORMATION OF PATAGONIA.

I will here describe in more detail than has been as yet incidentally done, the nature, origin, and extent of the great shingle covering of Patagonia: but I do not mean to affirm that all of this shingle, especially that on the higher plains, belongs to the recent period. A thin bed of sandy earth, with small pebbles of various porphyries and of quartz, covering a low plain on the north side of the Rio Colorado, is the extreme northern limit of this formation. These little pebbles have probably been derived from the denudation of a more regular bed of gravel, capping the old tertiary sandstone plateau of the Rio Negro. The gravel-bed near the Rio Negro is, on an average, about ten or twelve feet in thickness; and the pebbles are larger than on the northern side of the Colorado, being from one or two inches in diameter, and composed chiefly of rather dark-tinted porphyries. Amongst them I here first noticed a variety often to be referred to, namely, a peculiar gallstone-yellow siliceous porphyry, frequently, but not invariably, containing grains of quartz. The pebbles are embedded in a white, gritty, calcareous matrix, very like mortar, sometimes merely coating with a whitewash the separate stones, and sometimes forming the greater part of the mass. In one place I saw in the gravel concretionary nodules (not rounded) of crystallised gypsum, some as large as a man's head. I traced this

bed for forty-five miles inland, and was assured that it extended far into the interior. As the surface of the calcareo- argillaceous plain of Pampean formation, on the northern side of the wide valley of the Colorado, stands at about the same height with the mortar- like cemented gravel capping the sandstone on the southern side, it is probable, considering the apparent equability of the subterranean movements along this side of America, that this gravel of the Rio Negro and the upper beds of the Pampean formation northward of the Colorado, are of nearly contemporaneous origin, and that the calcareous matter has been derived from the same source.

Southward of the Rio Negro, the cliffs along the great bay of S. Antonio are capped with gravel: at San Josef, I found that the pebbles closely resembled those on the plain of the Rio Negro, but that they were not cemented by calcareous matter. Between San Josef and Port Desire, I was assured by the Officers of the Survey that the whole face of the country is coated with gravel. At Port Desire and over a space of twenty-five miles inland, on the three step-formed plains and in the valleys, I everywhere passed over gravel which, where thickest, was between thirty and forty feet. Here, as in other parts of Patagonia, the gravel, or its sandy covering, was, as we have seen, often strewed with recent marine shells. The sandy covering sometimes fills up furrows in the gravel, as does the gravel in the underlying tertiary formations. The pebbles are frequently whitewashed and even cemented together by a peculiar, white, friable, aluminous,

fusible substance, which I believe is decomposed feldspar. At Port Desire, the gravel rested sometimes on the basal formation of porphyry, and sometimes on the upper or the lower denuded tertiary strata. It is remarkable that most of the porphyritic pebbles differ from those varieties of porphyry which occur here abundantly in situ. The peculiar gallstone-yellow variety was common, but less numerous than at Port S. Julian, where it formed nearly one-third of the mass of the gravel; the remaining part there consisting of pale grey and greenish porphyries with many crystals of feldspar. At Port S. Julian, I ascended one of the flat- topped hills, the denuded remnant of the highest plain, and found it, at the height of 950 feet, capped with the usual bed of gravel.

Near the mouth of the Santa Cruz, the bed of gravel on the 355 feet plain is from twenty to about thirty-five feet in thickness. The pebbles vary from minute ones to the size of a hen's egg, and even to that of half a man's head; they consist of paler varieties of porphyry than those found further northward, and there are fewer of the gallstone-yellow kind; pebbles of compact black clay-slate were here first observed. The gravel, as we have seen, covers the step-formed plains at the mouth, head, and on the sides of the great valley of the Santa Cruz. At a distance of 110 miles from the coast, the plain has risen to the height of 1,416 feet above the sea; and the gravel, with the associated great boulder formation, has attained a thickness of 212 feet. The plain, apparently with its usual gravel covering, slopes up to the foot of the Cordillera to the

height of between 3,200 and 3,300 feet. In ascending the valley, the gravel gradually becomes entirely altered in character: high up, we have pebbles of crystalline feldspathic rocks, compact clay-slate, quartzose schists, and pale-coloured porphyries; these rocks, judging both from the gigantic boulders in the surface and from some small pebbles embedded beneath 700 feet in thickness of the old tertiary strata, are the prevailing kinds in this part of the Cordillera; pebbles of basalt from the neighbouring streams of basaltic lava are also numerous; there are few or none of the reddish or of the gallstone-yellow porphyries so common near the coast. Hence the pebbles on the 350 feet plain at the mouth of the Santa Cruz cannot have been derived (with the exception of those of compact clay- slate, which, however, may equally well have come from the south) from the Cordillera in this latitude; but probably, in chief part, from farther north.

Southward of the Santa Cruz, the gravel may be seen continuously capping the great 840 feet plain: at the Rio Gallegos, where this plain is succeeded by a lower one, there is, as I am informed by Captain Sulivan, an irregular covering of gravel from ten to twelve feet in thickness over the whole country. The district on each side of the Strait of Magellan is covered up either with gravel or the boulder formation: it was interesting to observe the marked difference between the perfectly rounded state of the pebbles in the great shingle formation of Patagonia, and the more or less angular fragments in the boulder formation. The pebbles and fragments near the Strait of Magellan nearly all

belong to rocks known to occur in Fuegia. I was therefore much surprised in dredging south of the Strait to find, in latitude 54 degrees 10' south, many pebbles of the gallstone-yellow siliceous porphyry; I procured others from a great depth off Staten Island, and others were brought me from the western extremity of the Falkland Islands. (At my request, Mr. Kent collected for me a bag of pebbles from the beach of White Rock harbour, in the northern part of the sound, between the two Falkland Islands. Out of these well-rounded pebbles, varying in size from a walnut to a hen's egg, with some larger, thirty-eight evidently belonged to the rocks of these islands; twenty-six were similar to the pebbles of porphyry found on the Patagonian plains, which rocks do not exist in situ in the Falklands; one pebble belonged to the peculiar yellow siliceous porphyry; thirty were of doubtful origin.) The distribution of the pebbles of this peculiar porphyry, which I venture to affirm is not found in situ either in Fuegia, the Falkland Islands, or on the coast of Patagonia, is very remarkable, for they are found over a space of 840 miles in a north and south line, and at the Falklands, 300 miles eastward of the coast of Patagonia. Their occurrence in Fuegia and the Falklands may, however, perhaps be due to the same ice-agency by which the boulders have been there transported.

We have seen that porphyritic pebbles of a small size are first met with on the northern side of the Rio Colorado, the bed becoming well developed near the Rio Negro: from this latter point I have every reason to believe that the gravel extends

uninterruptedly over the plains and valleys of Patagonia for at least 630 nautical miles southward to the Rio Gallegos. From the slope of the plains, from the nature of the pebbles, from their extension at the Rio Negro far into the interior, and at the Santa Cruz close up to the Cordillera, I think it highly probable that the whole breadth of Patagonia is thus covered. If so, the average width of the bed must be about two hundred miles. Near the coast the gravel is generally from ten to thirty feet in thickness; and as in the valley of Santa Cruz it attains, at some distance from the Cordillera, a thickness of 214 feet, we may, I think, safely assume its average thickness over the whole area of 630 by 200 miles, at fifty feet!

The transportal and origin of this vast bed of pebbles is an interesting problem. From the manner in which they cap the step-formed plains, worn by the sea within the period of existing shells, their deposition, at least on the plains up to a height of 400 feet, must have been a recent geological event. From the form of the continent, we may feel sure that they have come from the westward, probably, in chief part from the Cordillera, but, perhaps, partly from unknown rocky ridges in the central districts of Patagonia. That the pebbles have not been transported by rivers, from the interior towards the coast, we may conclude from the fewness and smallness of the streams of Patagonia: moreover, in the case of the one great and rapid river of Santa Cruz, we have good evidence that its transporting power is very trifling. This river is from two to three hundred

yards in width, about seventeen feet deep in its middle, and runs with a singular degree of uniformity five knots an hour, with no lakes and scarcely any still reaches: nevertheless, to give one instance of its small transporting power, upon careful examination, pebbles of compact basalt could not be found in the bed of the river at a greater distance than ten miles below the point where the stream rushes over the debris of the great basaltic cliffs forming its shore: fragments of the CELLULAR varieties have been washed down twice or thrice as far. That the pebbles in Central and Northern Patagonia have not been transported by ice-agency, as seems to have been the case to a considerable extent farther south, and likewise in the northern hemisphere, we may conclude, from the absence of all angular fragments in the gravel, and from the complete contrast in many other respects between the shingle and neighbouring boulder formation.

Looking to the gravel on any one of the step-formed plains, I cannot doubt, from the several reasons assigned in this chapter, that it has been spread out and leveled by the long-continued action of the sea, probably during the slow rise of the land. The smooth and perfectly rounded condition of the innumerable pebbles alone would prove long-continued action. But how the whole mass of shingle on the coast-plains has been transported from the mountains of the interior, is another and more difficult question. The following considerations, however, show that the sea by its ordinary action has considerable power in distributing pebbles. Table 3 above shows how very uniformly

and gradually the pebbles decrease in size with the gradually seaward increasing depth and distance. (I may mention, that at the distance of 150 miles from the Patagonian shore I carefully examined the minute rounded particles in the sand, and found them to be fusible like the porphyries of the great shingle bed. I could even distinguish particles of the gallstone-yellow porphyry. It was interesting to notice how gradually the particles of white quartz increased, as we approached the Falkland Islands, which are thus constituted. In the whole line of soundings between these islands and the coast of Patagonia dead or living organic remains were most rare. On the relations between the depth of water and the nature of the bottom, see Martin White on "Soundings in the Channel" pages 4, 6, 175; also Captain Beechey's "Voyage to the Pacific" chapter 18.) A series of this kind irresistibly leads to the conclusion, that the sea has the power of sifting and distributing the loose matter on its bottom. According to Martin White, the bed of the British Channel is disturbed during gales at depths of sixty-three and sixty-seven fathoms, and at thirty fathoms, shingle and fragments of shells are often deposited, afterwards to be carried away again. ("Soundings in the Channel" pages 4, 166. M. Siau states ("Edinburgh New Philosophical Journal" volume 31 page 246), that he found the sediment, at a depth of 188 metres, arranged in ripples of different degrees of fineness. There are some excellent discussions on this and allied subjects in Sir H. De la Beche's "Theoretical Researches.") Groundswells, which are believed to be caused by distant gales,

seem especially to affect the bottom: at such times, according to Sir R. Schomburgk, the sea to a great distance round the West Indian Islands, at depths from five to fifteen fathoms, becomes discoloured, and even the anchors of vessels have been moved. ("Journal of Royal Geographical Society" volume 5 page 25. It appears from Mr. Scott Russell's investigations (see Mr. Murchison's "Anniversary Address Geological Society" 1843 page 40), that in waves of translation the motion of the particles of water is nearly as great at the bottom as at the top.) There are, however, some difficulties in understanding how the sea can transport pebbles lying at the bottom, for, from experiments instituted on the power of running water, it would appear that the currents of the sea have not sufficient velocity to move stones of even moderate size: moreover, I have repeatedly found in the most exposed situations that the pebbles which lie at the bottom are encrusted with full-grown living corallines, furnished with the most delicate, yet unbroken spines: for instance, in ten fathoms water off the mouth of the Santa Cruz, many pebbles, under half an inch in diameter, were thus coated with Flustracean zoophytes. (A pebble, one and a half inch square and half an inch thick, was given me, dredged up from twenty-seven fathoms depth off the western end of the Falkland Islands, where the sea is remarkably stormy, and subject to violent tides. This pebble was encrusted on all sides by a delicate living coralline. I have seen many pebbles from depths between forty and seventy fathoms thus encrusted; one from the latter depth off Cape Horn.) Hence

we must conclude that these pebbles are not often violently disturbed: it should, however, be borne in mind that the growth of corallines is rapid. The view, propounded by Professor Playfair, will, I believe, explain this apparent difficulty, – namely, that from the undulations of the sea TENDING to lift up and down pebbles or other loose bodies at the bottom, such are liable, when thus quite or partially raised, to be moved even by a very small force, a little onwards. We can thus understand how oceanic or tidal currents of no great strength, or that recoil movement of the bottom-water near the land, called by sailors the "undertow" (which I presume must extend out seaward as far as the BREAKING waves impel the surface-water towards the beach), may gain the power during storms of sifting and distributing pebbles even of considerable size, and yet without so violently disturbing them as to injure the encrusting corallines. (I may take this opportunity of remarking on a singular, but very common character in the form of the bottom, in the creeks which deeply penetrate the western shores of Tierra del Fuego; namely, that they are almost invariably much shallower close to the open sea at their mouths than inland. Thus, Cook, in entering Christmas Sound, first had soundings in thirty-seven fathoms, then in fifty, then in sixty, and a little farther in no bottom with 170 fathoms. The sealers are so familiar with this fact, that they always look out for anchorage near the entrances of the creeks. See, also, on this subject, the "Voyages of the 'Adventure' and 'Beagle'" volume 1 page 375 and "Appendix" page 313. This

Shoalness of the sea- channels near their entrances probably results from the quantity of sediment formed by the wear and tear of the outer rocks exposed to the full force of the open sea. I have no doubt that many lakes, for instance in Scotland, which are very deep within, and are separated from the sea apparently only by a tract of detritus, were originally sea-channels with banks of this nature near their mouths, which have since been upheaved.)

The sea acts in another and distinct manner in the distribution of pebbles, namely by the waves on the beach. Mr. Palmer, in his excellent memoir on this subject, has shown that vast masses of shingle travel with surprising quickness along lines of coast, according to the direction with which the waves break on the beach and that this is determined by the prevailing direction of the winds. ("Philosophical Transactions" 1834 page 576.) This agency must be powerful in mingling together and disseminating pebbles derived from different sources: we may, perhaps, thus understand the wide distribution of the gallstone-yellow porphyry; and likewise, perhaps, the great difference in the nature of the pebbles at the mouth of the Santa Cruz from those in the same latitude at the head of the valley.

I will not pretend to assign to these several and complicated agencies their shares in the distribution of the Patagonian shingle: but from the several considerations given in this chapter, and I may add, from the frequency of a capping of gravel on tertiary deposits in all parts of the world, as I have myself observed and seen stated in the works of various authors, I cannot doubt that

the power of widely dispersing gravel is an ordinary contingent on the action of the sea; and that even in the case of the great Patagonian shingle-bed we have no occasion to call in the aid of debacles. I at one time imagined that perhaps an immense accumulation of shingle had originally been collected at the foot of the Cordillera; and that this accumulation, when upraised above the level of the sea, had been eaten into and partially spread out (as off the present line of coast); and that the newly-spread out bed had in its turn been upraised, eaten into, and re-spread out; and so onwards, until the shingle, which was first accumulated in great thickness at the foot of the Cordillera, had reached in thinner beds its present extension. By whatever means the gravel formation of Patagonia may have been distributed, the vastness of its area, its thickness, its superficial position, its recent origin, and the great degree of similarity in the nature of its pebbles, all appear to me well deserving the attention of geologists, in relation to the origin of the widely-spread beds of conglomerate belonging to past epochs.

FORMATION OF CLIFFS.

(DIAGRAM 7. – SECTION OF COAST-CLIFFS AND BOTTOM OF SEA, OFF THE ISLAND OF ST. HELENA.

Height in feet above sea level.

Depths in fathoms.

Vertical and horizontal scale, two inches to a nautical mile. The point marked 1,600 feet is at the foot of High Knoll; point marked 510 feet is on the edge of Ladder Hill. The strata consist

of basaltic streams.

Section left to right:

Height at the foot of High Knoll: 1,600 at top of strata.

Height on the edge of Ladder Hill: 510 at top of strata.

Bottom at coast rocky only to a depth of five or six fathoms.

30 fathoms: bottom mud and sand.

100 fathoms sloping more sharply to 250 fathoms.)

When viewing the sea-worn cliffs of Patagonia, in some parts between eight hundred and nine hundred feet in height, and formed of horizontal tertiary strata, which must once have extended far seaward – or again, when viewing the lofty cliffs round many volcanic islands, in which the gentle inclination of the lava-streams indicates the former extension of the land, a difficulty often occurred to me, namely, how the strata could possibly have been removed by the action of the sea at a considerable depth beneath its surface. The section in Diagram 7, which represents the general form of the land on the northern and leeward side of St. Helena (taken from Mr. Seale's large model and various measurements), and of the bottom of the adjoining sea (taken chiefly from Captain Austin's survey and some old charts), will show the nature of this difficulty.

If, as seems probable, the basaltic streams were originally prolonged with nearly their present inclination, they must, as shown by the dotted line in the section, once have extended at least to a point, now covered by the sea to a depth of nearly thirty fathoms: but I have every reason to believe they extended

considerably further, for the inclination of the streams is less near the coast than further inland. It should also be observed, that other sections on the coast of this island would have given far more striking results, but I had not the exact measurements; thus, on the windward side, the cliffs are about two thousand feet in height and the cut-off lava streams very gently inclined, and the bottom of the sea has nearly a similar slope all round the island. How, then, has all the hard basaltic rock, which once extended beneath the surface of the sea, been worn away? According to Captain Austin, the bottom is uneven and rocky only to that very small distance from the beach within which the depth is from five to six fathoms; outside this line, to a depth of about one hundred fathoms, the bottom is smooth, gently inclined, and formed of mud and sand; outside the one hundred fathoms, it plunges suddenly into unfathomable depths, as is so very commonly the case on all coasts where sediment is accumulating. At greater depths than the five or six fathoms, it seems impossible, under existing circumstances, that the sea can both have worn away hard rock, in parts to a thickness of at least 150 feet, and have deposited a smooth bed of fine sediment. Now, if we had any reason to suppose that St. Helena had, during a long period, gone on slowly subsiding, every difficulty would be removed: for looking at the diagram, and imagining a fresh amount of subsidence, we can see that the waves would then act on the coast-cliffs with fresh and unimpaired vigour, whilst the rocky ledge near the beach would be carried down to that depth, at

which sand and mud would be deposited on its bare and uneven surface: after the formation near the shore of a new rocky shoal, fresh subsidence would carry it down and allow it to be smoothly covered up. But in the case of the many cliff-bounded islands, for instance in some of the Canary Islands and of Madeira, round which the inclination of the strata shows that the land once extended far into the depths of the sea, where there is no apparent means of hard rock being worn away – are we to suppose that all these islands have slowly subsided? Madeira, I may remark, has, according to Mr. Smith of Jordan Hill, subsided. Are we to extend this conclusion to the high, cliff- bound, horizontally stratified shores of Patagonia, off which, though the water is not deep even at the distance of several miles, yet the smooth bottom of pebbles gradually decreasing in size with the increasing depth, and derived from a foreign source, seem to declare that the sea is now a depositing and not a corroding agent? I am much inclined to suspect, that we shall hereafter find in all such cases, that the land with the adjoining bed of the sea has in truth subsided: the time will, I believe, come, when geologists will consider it as improbable, that the land should have retained the same level during a whole geological period, as that the atmosphere should have remained absolutely calm during an entire season.

CHAPTER II. ON THE ELEVATION OF THE WESTERN COAST OF SOUTH AMERICA

Chonos Archipelago.

Chiloe, recent and gradual elevation of, traditions of the inhabitants on this subject.

Concepcion, earthquake and elevation of.

VALPARAISO, great elevation of, upraised shells, earth of marine origin, gradual rise of the land within the historical period.

COQUIMBO, elevation of, in recent times; terraces of marine origin, their inclination, their escarpments not horizontal.

Guasco, gravel terraces of.

Copiapo.

PERU.

Upraised shells of Cobija, Iquique, and Arica.

Lima, shell-beds and sea-beach on San Lorenzo, human remains, fossil earthenware, earthquake debacle, recent subsidence.

On the decay of upraised shells.

General summary.

Commencing at the south and proceeding northward, the first place at which I landed, was at Cape Tres Montes, in latitude 46

degrees 35'. Here, on the shores of Christmas Cove, I observed in several places a beach of pebbles with recent shells, about twenty feet above high-water mark. Southward of Tres Montes (between latitude 47 and 48 degrees), Byron remarks, "We thought it very strange, that upon the summits of the highest hills were found beds of shells, a foot or two thick." ("Narrative of the Loss of the 'Wager'.") In the Chonos Archipelago, the island of Lemus (latitude 44 degrees 30') was, according to M. Coste, suddenly elevated eight feet, during the earthquake of 1829: he adds, "Des roches jadis toujours couvertes par la mer, restant aujourd'hui constamment decouvertes." ("Comptes Rendus" October 1838 page 706.) In other parts of this archipelago, I observed two terraces of gravel, abutting to the foot of each other: at Lowe's Harbour (43 degrees 48'), under a great mass of the boulder formation, about three hundred feet in thickness, I found a layer of sand, with numerous comminuted fragments of sea-shells, having a fresh aspect, but too small to be identified.

THE ISLAND OF CHILOE.

The evidence of recent elevation is here more satisfactory. The bay of San Carlos is in most parts bounded by precipitous cliffs from about ten to forty feet in height, their bases being separated from the present line of tidal action by a talus, a few feet in height, covered with vegetation. In one sheltered creek (west of P. Arena), instead of a loose talus, there was a bare sloping bank of tertiary mudstone, perforated, above the line of the highest tides, by numerous shells of a Pholas now common

in the harbour. The upper extremities of these shells, standing upright in their holes with grass growing out of them, were abraded about a quarter of an inch, to the same level with the surrounding worn strata. In other parts, I observed (as at Pudeto) a great beach, formed of comminuted shells, twenty feet above the present shore. In other parts again, there were small caves worn into the foot of the low cliffs, and protected from the waves by the talus with its vegetation: one such cave, which I examined, had its mouth about twenty feet, and its bottom, which was filled with sand containing fragments of shells and legs of crabs, from eight to ten feet above high-water mark. From these several facts, and from the appearance of the upraised shells, I inferred that the elevation had been quite recent; and on inquiring from Mr. Williams, the Portmaster, he told me he was convinced that the land had risen, or the sea fallen, four feet within the last four years. During this period, there had been one severe earthquake, but no particular change of level was then observed; from the habits of the people who all keep boats in the protected creeks, it is absolutely impossible that a rise of four feet could have taken place suddenly and been unperceived. Mr. Williams believes that the change has been quite gradual. Without the elevatory movement continues at a quick rate, there can be no doubt that the sea will soon destroy the talus of earth at the foot of the cliffs round the bay, and will then reach its former lateral extension, but not of course its former level: some of the inhabitants assured me that one such talus, with a footpath on it, was even already

sensibly decreasing in width.

I received several accounts of beds of shells, existing at considerable heights in the inland parts of Chiloe; and to one of these, near Catiman, I was guided by a countryman. Here, on the south side of the peninsula of Lacuy, there was an immense bed of the Venus costellata and of an oyster, lying on the summit-edge of a piece of tableland, 350 feet (by the barometer) above the level of the sea. The shells were closely packed together, embedded in and covered by a very black, damp, peaty mould, two or three feet in thickness, out of which a forest of great trees was growing. Considering the nature and dampness of this peaty soil, it is surprising that the fine ridges on the outside of the Venus are perfectly preserved, though all the shells have a blackened appearance. I did not doubt that the black soil, which when dry, cakes hard, was entirely of terrestrial origin, but on examining it under the microscope, I found many very minute rounded fragments of shells, amongst which I could distinguish bits of Serpulae and mussels. The Venus costellata, and the Ostrea (O. edulis, according to Captain King) are now the commonest shells in the adjoining bays. In a bed of shells, a few feet below the 350 feet bed, I found a horn of the little Cervus humilis, which now inhabits Chiloe.

The eastern or inland side of Chiloe, with its many adjacent islets, consists of tertiary and boulder deposits, worn into irregular plains capped by gravel. Near Castro, and for ten miles southward, and on the islet of Lemuy, I found the surface of

the ground to a height of between twenty and thirty feet above high-water mark, and in several places apparently up to fifty feet, thickly coated by much comminuted shells, chiefly of the Venus costellata and Mytilus Chiloensis; the species now most abundant on this line of coast. As the inhabitants carry immense numbers of these shells inland, the continuity of the bed at the same height was often the only means of recognising its natural origin. Near Castro, on each side of the creek and rivulet of the Gamboa, three distinct terraces are seen: the lowest was estimated at about one hundred and fifty feet in height, and the highest at about five hundred feet, with the country irregularly rising behind it; obscure traces, also, of these same terraces could be seen along other parts of the coast. There can be no doubt that their three escarpments record pauses in the elevation of the island. I may remark that several promontories have the word Huapi, which signifies in the Indian tongue, island, appended to them, such as Huapilinao, Huapilacuy, Caucahuapi, etc.; and these, according to Indian traditions, once existed as islands. In the same manner the term Pulo in Sumatra is appended to the names of promontories, traditionally said to have been islands (Marsden's "Sumatra" page 31.); in Sumatra, as in Chiloe, there are upraised recent shells. The Bay of Carelmapu, on the mainland north of Chiloe, according to Aguerros, was in 1643 a good harbour ("Descripcion Hist. de la Provincia de Chiloe" page 78. From the account given by the old Spanish writers, it would appear that several other harbours, between this point and

Concepcion, were formerly much deeper than they now are.); it is now quite useless, except for boats.

VALDIVIA.

I did not observe here any distinct proofs of recent elevation; but in a bed of very soft sandstone, forming a fringe-like plain, about sixty feet in height, round the hills of mica-slate, there are shells of Mytilus, Crepidula, Solen, Novaculina, and Cytheraea, too imperfect to be specifically recognised. At Imperial, seventy miles north of Valdivia, Aguerros states that there are large beds of shells, at a considerable distance from the coast, which are burnt for lime. (Ibid page 25.) The island of Mocha, lying a little north of Imperial, was uplifted two feet, during the earthquake of 1835. ("Voyages of 'Adventure' and 'Beagle'" volume 2 page 415.)

CONCEPCION.

I cannot add anything to the excellent account by Captain Fitzroy of the elevation of the land at this place, which accompanied the earthquake of 1835. (Ibid volume 2 page 412 et seq. In volume 5 page 601 of the "Geological Transactions" I have given an account of the remarkable volcanic phenomena, which accompanied this earthquake. These phenomena appear to me to prove that the action, by which large tracts of land are uplifted, and by which volcanic eruptions are produced, is in every respect identical.) I will only recall to the recollection of geologists, that the southern end of the island of St. Mary was uplifted eight feet, the central part nine, and the northern end ten

feet; and the whole island more than the surrounding districts. Great beds of mussels, patellae, and chitons still adhering to the rocks were upraised above high-water mark; and some acres of a rocky flat, which was formerly always covered by the sea, was left standing dry, and exhaled an offensive smell, from the many attached and putrefying shells. It appears from the researches of Captain Fitzroy that both the island of St. Mary and Concepcion (which was uplifted only four or five feet) in the course of some weeks subsided, and lost part of their first elevation. I will only add as a lesson of caution, that round the sandy shores of the great Bay of Concepcion, it was most difficult, owing to the obliterating effects of the great accompanying wave, to recognise any distinct evidence of this considerable upheaval; one spot must be excepted, where there was a detached rock which before the earthquake had always been covered by the sea, but afterwards was left uncovered.

On the island of Quiriquina (in the Bay of Concepcion), I found, at an estimated height of four hundred feet, extensive layers of shells, mostly comminuted, but some perfectly preserved and closely packed in black vegetable mould; they consisted of Concholepas, Fissurella, Mytilus, Trochus, and Balanus. Some of these layers of shells rested on a thick bed of bright-red, dry, friable earth, capping the surface of the tertiary sandstone, and extending, as I observed whilst sailing along the coast, for 150 miles southward: at Valparaiso, we shall presently see that a similar red earthy mass, though quite like terrestrial

mould, is really in chief part of recent marine origin. On the flanks of this island of Quiriquina, at a less height than the 400 feet, there were spaces several feet square, thickly strewed with fragments of similar shells. During a subsequent visit of the "Beagle" to Concepcion, Mr. Kent, the assistant-surgeon, was so kind as to make for me some measurements with the barometer: he found many marine remains along the shores of the whole bay, at a height of about twenty feet; and from the hill of Sentinella behind Talcahuano, at the height of 160 feet, he collected numerous shells, packed together close beneath the surface in black earth, consisting of two species of Mytilus, two of Crepidula, one of Concholepas, of Fissurella, Venus, Mactra, Turbo, Monoceros, and the Balanus psittacus. These shells were bleached, and within some of the Balani other Balani were growing, showing that they must have long lain dead in the sea. The above species I compared with living ones from the bay, and found them identical; but having since lost the specimens, I cannot give their names: this is of little importance, as Mr. Broderip has examined a similar collection, made during Captain Beechey's expedition, and ascertained that they consisted of ten recent species, associated with fragments of Echini, crabs, and Flustrae; some of these remains were estimated by Lieutenant Belcher to lie at the height of nearly a thousand feet above the level of the sea. ("Zoology of Captain Beechey's Voyage" page 162.) In some places round the bay, Mr. Kent observed that there were beds formed exclusively of the Mytilus Chiloensis:

this species now lives in parts never uncovered by the tides. At considerable heights, Mr. Kent found only a few shells; but from the summit of one hill, 625 feet high, he brought me specimens of the Concholepas, Mytilus Chiloensis, and a Turbo. These shells were softer and more brittle than those from the height of 164 feet; and these latter had obviously a much more ancient appearance than the same species from the height of only twenty feet.

COAST NORTH OF CONCEPCION.

The first point examined was at the mouth of the Rapel (160 miles north of Concepcion and sixty miles south of Valparaiso), where I observed a few shells at the height of 100 feet, and some barnacles adhering to the rocks three or four feet above the highest tides: M. Gay found here recent shells at the distance of two leagues from the shore. ("Annales des Scienc. Nat." Avril 1833.) Inland there are some wide, gravel-capped plains, intersected by many broad, flat-bottomed valleys (now carrying insignificant streamlets), with their sides cut into successive wall-like escarpments, rising one above another, and in many places, according to M. Gay, worn into caves. The one cave (C. del Obispo) which I examined, resembled those formed on many sea-coasts, with its bottom filled with shingle. These inland plains, instead of sloping towards the coast, are inclined in an opposite direction towards the Cordillera, like the successively rising terraces on the inland or eastern side of Chiloe: some points of granite, which project through the plains near the coast,

no doubt once formed a chain of outlying islands, on the inland shores of which the plains were accumulated. At Bucalemu, a few miles northward of the Rapel, I observed at the foot, and on the summit-edge of a plain, ten miles from the coast, many recent shells, mostly comminuted, but some perfect. There were, also, many at the bottom of the great valley of the Maypu. At San Antonio, shells are said to be collected and burnt for lime. At the bottom of a great ravine (Quebrada Onda, on the road to Casa Blanca), at the distance of several miles from the coast, I noticed a considerable bed, composed exclusively of Mesodesma donaciforme, Desh., lying on a bed of muddy sand: this shell now lives associated together in great numbers, on tidal-flats on the coast of Chile.

VALPARAISO.

During two successive years I carefully examined, part of the time in company with Mr. Alison, into all the facts connected with the recent elevation of this neighbourhood. In very many parts a beach of broken shells, about fourteen or fifteen feet above high-water mark, may be observed; and at this level the coast-rocks, where precipitous, are corroded in a band. At one spot, Mr. Alison, by removing some birds' dung, found at this same level barnacles adhering to the rocks. For several miles southward of the bay, almost every flat little headland, between the heights of 60 and 230 feet (measured by the barometer), is smoothly coated by a thick mass of comminuted shells, of the same species, and apparently in the

same proportional numbers with those existing in the adjoining sea. The Concholepas is much the most abundant, and the best preserved shell; but I extracted perfectly preserved specimens of the Fissurella biradiata, a Trochus and Balanus (both well-known, but according to Mr. Sowerby yet unnamed) and parts of the Mytilus Chiloensis. Most of these shells, as well as an encrusting Nullipora, partially retain their colour; but they are brittle, and often stained red from the underlying brecciated mass of primary rocks; some are packed together, either in black or reddish moulds; some lie loose on the bare rocky surfaces. The total number of these shells is immense; they are less numerous, though still far from rare, up a height of 1,000 feet above the sea. On the summit of a hill, measured 557 feet, there was a small horizontal band of comminuted shells, of which MANY consisted (and likewise from lesser heights) of very young and small specimens of the still living Concholepas, Trochus, Patellae, Crepidulae, and of Mytilus Magellanicus (?) (Mr. Cuming informs me that he does not think this species identical with, though closely resembling, the true M. Magellanicus of the southern and eastern coast of South America; it lives abundantly on the coast of Chile.): several of these shells were under a quarter of an inch in their greatest diameter. My attention was called to this circumstance by a native fisherman, whom I took to look at these shell-beds; and he ridiculed the notion of such small shells having been brought up for food; nor could some of the species have adhered when alive to other larger shells. On

another hill, some miles distant, and 648 feet high, I found shells of the Concholepas and Trochus, perfect, though very old, with fragments of Mytilus Chiloensis, all embedded in reddish-brown mould: I also found these same species, with fragments of an Echinus and of Balanus psittacus, on a hill 1,000 feet high. Above this height, shells became very rare, though on a hill 1,300 feet high (Measured by the barometer: the highest point in the range behind Valparaiso I found to be 1,626 feet above the level of the sea.), I collected the Concholepas, Trochus, Fissurella, and a Patella. At these greater heights the shells are almost invariably embedded in mould, and sometimes are exposed only by tearing up bushes. These shells obviously had a very much more ancient appearance than those from the lesser heights; the apices of the Trochi were often worn down; the little holes made by burrowing animals were greatly enlarged; and the Concholepas was often perforated quite through, owing to the inner plates of shell having scaled off.

Many of these shells, as I have said, were packed in, and were quite filled with, blackish or reddish-brown earth, resting on the granitic detritus. I did not doubt until lately that this mould was of purely terrestrial origin, when with a microscope examining some of it from the inside of a Concholepas from the height of about one hundred feet, I found that it was in considerable part composed of minute fragments of the spines, mouth- bones, and shells of Echini, and of minute fragments, of chiefly very young Patellae, Mytili, and other species. I found

similar microscopical fragments in earth filling up the central orifices of some large Fissurellae. This earth when crushed emits a sickly smell, precisely like that from garden-mould mixed with guano. The earth accidentally preserved within the shells, from the greater heights, has the same general appearance, but it is a little redder; it emits the same smell when rubbed, but I was unable to detect with certainty any marine remains in it. This earth resembles in general appearance, as before remarked, that capping the rocks of Quiriquina in the Bay of Concepcion, on which beds of sea-shells lay. I have, also, shown that the black, peaty soil, in which the shells at the height of 350 feet at Chiloe were packed, contained many minute fragments of marine animals. These facts appear to me interesting, as they show that soils, which would naturally be considered of purely terrestrial nature, may owe their origin in chief part to the sea.

Being well aware from what I have seen at Chiloe and in Tierra del Fuego, that vast quantities of shells are carried, during successive ages, far inland, where the inhabitants chiefly subsist on these productions, I am bound to state that at greater heights than 557 feet, where the number of very young and small shells proved that they had not been carried up for food, the only evidence of the shells having been naturally left by the sea, consists in their invariable and uniform appearance of extreme antiquity – in the distance of some of the places from the coast, in others being inaccessible from the nearest part of the beach, and in the absence of fresh water for men to drink – in the shells

NOT LYING IN HEAPS, – and, lastly, in the close similarity of the soil in which they are embedded, to that which lower down can be unequivocally shown to be in great part formed from the debris of the sea animals. (In the "Proceedings of the Geological Society" volume 2 page 446, I have given a brief account of the upraised shells on the coast of Chile, and have there stated that the proofs of elevation are not satisfactory above the height of 230 feet. I had at that time unfortunately overlooked a separate page written during my second visit to Valparaiso, describing the shells now in my possession from the 557 feet hill; I had not then unpacked my collections, and had not reconsidered the obvious appearance of greater antiquity of the shells from the greater heights, nor had I at that time discovered the marine origin of the earth in which many of the shells are packed. Considering these facts, I do not now feel a shadow of doubt that the shells, at the height of 1,300 feet, have been upraised by natural causes into their present position.)

With respect to the position in which the shells lie, I was repeatedly struck here, at Concepcion, and at other places, with the frequency of their occurrence on the summits and edges either of separate hills, or of little flat headlands often terminating precipitously over the sea. The several above-enumerated species of mollusca, which are found strewed on the surface of the land from a few feet above the level of the sea up to the height of 1,300 feet, all now live either on the beach, or at only a few fathoms' depth: Mr. Edmondston, in a letter to Professor

E. Forbes, states that in dredging in the Bay of Valparaiso, he found the common species of Concholepas, Fissurella, Trochus, Monoceros, Chitons, etc., living in abundance from the beach to a depth of seven fathoms; and dead shells occurred only a few fathoms deeper. The common Turritella cingulata was dredged up living at even from ten to fifteen fathoms; but this is a species which I did not find here amongst the upraised shells. Considering this fact of the species being all littoral or sub-littoral, considering their occurrence at various heights, their vast numbers, and their generally comminuted state, there can be little doubt that they were left on successive beach-lines during a gradual elevation of the land. The presence, however, of so many whole and perfectly preserved shells appears at first a difficulty on this view, considering that the coast is exposed to the full force of an open ocean: but we may suppose, either that these shells were thrown during gales on flat ledges of rock just above the level of high-water mark, and that during the elevation of the land they are never again touched by the waves, or, that during earthquakes, such as those of 1822, 1835, and 1837, rocky reefs covered with marine-animals were it one blow uplifted above the future reach of the sea. This latter explanation is, perhaps, the most probable one with respect to the beds at Concepcion entirely composed of the Mytilus Chiloensis, a species which lives below the lowest tides; and likewise with respect to the great beds occurring both north and south of Valparaiso, of the Mesodesma donaciforme, – a shell which, as I am informed by

Mr. Cuming, inhabits sandbanks at the level of the lowest tides. But even in the case of shells having the habits of this Mytilus and Mesodesma, beds of them, wherever the sea gently throws up sand or mud, and thus protects its own accumulations, might be upraised by the slowest movement, and yet remain undisturbed by the waves of each new beach-line.

It is worthy of remark, that nowhere near Valparaiso above the height of twenty feet, or rarely of fifty feet, I saw any lines of erosion on the solid rocks, or any beds of pebbles; this, I believe, may be accounted for by the disintegrating tendency of most of the rocks in this neighbourhood. Nor is the land here modelled into terraces: Mr. Alison, however, informs me, that on both sides of one narrow ravine, at the height of 300 feet above the sea, he found a succession of rather indistinct step-formed beaches, composed of broken shells, which together covered a space of about eighty feet vertical.

I can add nothing to the accounts already published of the elevation of the land at Valparaiso, which accompanied the earthquake of 1822 (Dr. Meyen "Reise um Erde" Th. 1 s. 221, found in 1831 seaweed and other bodies still adhering to some rocks which during the shock of 1822 were lifted above the sea.): but I heard it confidently asserted, that a sentinel on duty, immediately after the shock, saw a part of a fort, which previously was not within the line of his vision, and this would indicate that the uplifting was not horizontal: it would even appear from some facts collected by Mr. Alison, that only the

eastern half of the bay was then elevated. Through the kindness of this same gentleman, I am able to give an interesting account of the changes of level, which have supervened here within historical periods: about the year 1680 a long sea-wall (or Prefil) was built, of which only a few fragments now remain; up to the year 1817, the sea often broke over it, and washed the houses on the opposite side of the road (where the prison now stands); and even in 1819, Mr. J. Martin remembers walking at the foot of this wall, and being often obliged to climb over it to escape the waves. There now stands (1834) on the seaward side of this wall, and between it and the beach, in one part a single row of houses, and in another part two rows with a street between them. This great extension of the beach in so short a time cannot be attributed simply to the accumulation of detritus; for a resident engineer measured for me the height between the lowest part of the wall visible, and the present beach-line at spring-tides, and the difference was eleven feet six inches. The church of S. Augustin is believed to have been built in 1614, and there is a tradition that the sea formerly flowed very near it; by levelling, its foundations were found to stand nineteen feet six inches above the highest beach-line; so that we see in a period of 220 years, the elevation cannot have been as much as nineteen feet six inches. From the facts given with respect to the sea-wall, and from the testimony of the elder inhabitants, it appears certain that the change in level began to be manifest about the year 1817. The only sudden elevation of which there is any record occurred in

1822, and this seems to have been less than three feet. Since that year, I was assured by several competent observers, that part of an old wreck, which is firmly embedded near the beach, has sensibly emerged; hence here, as at Chiloe, a slow rise of the land appears to be now in progress. It seems highly probable that the rocks which are corroded in a band at the height of fourteen feet above the sea were acted on during the period, when by tradition the base of S. Augustin church, now nineteen feet six inches above the highest water-mark, was occasionally washed by the waves.

VALPARAISO TO COQUIMBO.

For the first seventy-five miles north of Valparaiso I followed the coast- road, and throughout this space I observed innumerable masses of upraised shells. About Quintero there are immense accumulations (worked for lime) of the Mesodesma donaciforme, packed in sandy earth; they abound chiefly about fifteen feet above high-water, but shells are here found, according to Mr. Miers, to a height of 500 feet, and at a distance of three leagues from the coast ("Travels in Chile" volume 1 pages 395, 458. I received several similar accounts from the inhabitants, and was assured that there are many shells on the plain of Casa Blanca, between Valparaiso and Santiago, at the height of 800 feet.): I here noticed barnacles adhering to the rocks three or four feet above the highest tides. In the neighbourhood of Plazilla and Catapilco, at heights of between two hundred and three hundred feet, the number of comminuted

shells, with some perfect ones, especially of the Mesodesma, packed in layers, was truly immense: the land at Plazilla had evidently existed as a bay, with abrupt rocky masses rising out of it, precisely like the islets in the broken bays now indenting this coast. On both sides of the rivers Ligua, Longotomo, Guachen, and Quilimari, there are plains of gravel about two hundred feet in height, in many parts absolutely covered with shells. Close to Conchalee, a gravel-plain is fronted by a lower and similar plain about sixty feet in height, and this again is separated from the beach by a wide tract of low land: the surfaces of all three plains or terraces were strewed with vast numbers of the Concholepas, Mesodesma, an existing Venus, and other still existing littoral shells. The two upper terraces closely resemble in miniature the plains of Patagonia; and like them are furrowed by dry, flat-bottomed, winding valleys. Northward of this place I turned inward; and therefore found no more shells: but the valleys of Chuapa, Illapel, and Limari, are bounded by gravel-capped plains, often including a lower terrace within. These plains send bay-like arms between and into the surrounding hills; and they are continuously united with other extensive gravel-capped plains, separating the coast mountain-ranges from the Cordillera.

COQUIMBO.

A narrow fringe-like plain, gently inclined towards the sea, here extends for eleven miles along the coast, with arms stretching up between the coast-mountains, and likewise up

the valley of Coquimbo: at its southern extremity it is directly connected with the plain of Limari, out of which hills abruptly rise like islets, and other hills project like headlands on a coast. The surface of the fringe-like plain appears level, but differs insensibly in height, and greatly in composition, in different parts.

At the mouth of the valley of Coquimbo, the surface consists wholly of gravel, and stands from 300 to 350 feet above the level of the sea, being about one hundred feet higher than in other parts. In these other and lower parts the superficial beds consist of calcareous matter, and rest on ancient tertiary deposits hereafter to be described. The uppermost calcareous layer is cream-coloured, compact, smooth-fractured, sub- stalactiform, and contains some sand, earthy matter, and recent shells. It lies on, and sends wedge-like veins into, a much more friable, calcareous, tuff-like variety; and both rest on a mass about twenty feet in thickness, formed of fragments of recent shells, with a few whole ones, and with small pebbles firmly cemented together. (In many respects this upper hard, and the underlying more friable, varieties, resemble the great superficial beds at King George's Sound in Australia, which I have described in my "Geological Observations on Volcanic Islands." There could be little doubt that the upper layers there have been hardened by the action of rain on the friable, calcareous matter, and that the whole mass has originated in the decay of minutely comminuted sea-shells and corals.) This latter rock is called by the inhabitants losa, and is used for building: in many parts it is divided into strata,

which dip at an angle of ten degrees seaward, and appear as if they had originally been heaped in successive layers (as may be seen on coral-reefs) on a steep beach. This stone is remarkable from being in parts entirely formed of empty, pellucid capsules or cells of calcareous matter, of the size of small seeds: a series of specimens unequivocally showed that all these capsules once contained minute rounded fragments of shells which have since been gradually dissolved by water percolating through the mass. (I have incidentally described this rock in the above work on Volcanic Islands.)

The shells embedded in the calcareous beds forming the surface of this fringe-like plain, at the height of from 200 to 250 feet above the sea, consist of: —

1. Venus opaca. 2. Mulinia Byronensis. 3. Pecten purpuratus. 4. Mesodesma donaciforme. 5. Turritella cingulata. 6. Monoceros costatum. 7. Concholepas Peruviana. 8. Trochus (common Valparaiso species). 9. Calyptraea Byronensis.

Although these species are all recent, and are all found in the neighbouring sea, yet I was particularly struck with the difference in the proportional numbers of the several species, and of those now cast up on the present beach. I found only one specimen of the Concholepas, and the Pecten was very rare, though both these shells are now the commonest kinds, with the exception, perhaps, of the Calyptraea radians, of which I did not find one in the calcareous beds. I will not pretend to determine how far this difference in the proportional numbers depends on the age

of the deposit, and how far on the difference in nature between the present sandy beaches and the calcareous bottom, on which the embedded shells must have lived.

(DIAGRAM 8. – SECTION OF PLAIN OF COQUIMBO.

Section through Plain B-B and Ravine A.

Surface of plain 252 feet above sea.

A. Stratified sand, with recent shells in same proportions as on the beach, half filling up a ravine.

B. Surface of plain, with scattered shells in nearly same proportions as on the beach.

C. Upper calcareous bed, and D. Lower calcareous sandy bed (Losa), both with recent shells, but not in same proportions as on the beach.

E. Upper ferrugino-sandy old tertiary stratum, and F. Lower old tertiary stratum, both with all, or nearly all, extinct shells.)

On the bare surface of the calcareous plain, or in a thin covering of sand, there were lying, at a height from 200 to 252 feet, many recent shells, which had a much fresher appearance than the embedded ones: fragments of the Concholepas, and of the common Mytilus, still retaining a tinge of its colour, were numerous, and altogether there was manifestly a closer approach in proportional numbers to those now lying on the beach. In a mass of stratified, slightly agglutinated sand, which in some places covers up the lower half of the seaward escarpment of the plain, the included shells appeared to be in exactly the same

proportional numbers with those on the beach. On one side of a steep-sided ravine, cutting through the plain behind Herradura Bay, I observed a narrow strip of stratified sand, containing similar shells in similar proportional numbers; a section of the ravine is represented in Diagram 8, which serves also to show the general composition of the plain. I mention this case of the ravine chiefly because without the evidence of the marine shells in the sand, any one would have supposed that it had been hollowed out by simple alluvial action.

The escarpment of the fringe-like plain, which stretches for eleven miles along the coast, is in some parts fronted by two or three narrow, step- formed terraces, one of which at Herradura Bay expands into a small plain. Its surface was there formed of gravel, cemented together by calcareous matter; and out of it I extracted the following recent shells, which are in a more perfect condition than those from the upper plain: —

1. Calyptraea radians. 2. Turritella cingulata. 3. Oliva Peruviana. 4. Murex labiosus, var. 5. Nassa (identical with a living species). 6. Solen Dombeiana. 7. Pecten purpuratus. 8. Venus Chilensis. 9. Amphidesma rugulosum. The small irregular wrinkles of the posterior part of this shell are rather stronger than in the recent specimens of this species from Coquimbo. (G.B. Sowerby.) 10. Balanus (identical with living species).

On the syenitic ridge, which forms the southern boundary of Herradura Bay and Plain, I found the Concholepas and Turritella cingulata (mostly in fragments), at the height of 242 feet above

the sea. I could not have told that these shells had not formerly been brought up by man, if I had not found one very small mass of them cemented together in a friable calcareous tuff. I mention this fact more particularly, because I carefully looked, in many apparently favourable spots, at lesser heights on the side of this ridge, and could not find even the smallest fragment of a shell. This is only one instance out of many, proving that the absence of sea-shells on the surface, though in many respects inexplicable, is an argument of very little weight in opposition to other evidence on the recent elevation of the land. The highest point in this neighbourhood at which I found upraised shells of existing species was on an inland calcareous plain, at the height of 252 feet above the sea.

It would appear from Mr. Caldcleugh's researches, that a rise has taken place here within the last century and a half ("Proceedings of the Geological Society" volume 2 page 446.); and as no sudden change of level has been observed during the not very severe earthquakes, which have occasionally occurred here, the rising has probably been slow, like that now, or quite lately, in progress at Chiloe and at Valparaiso: there are three well-known rocks, called the Pelicans, which in 1710, according to Feuillee, were a fleur d'eau, but now are said to stand twelve feet above low-water mark: the spring-tides rise here only five feet. There is another rock, now nine feet above high-water mark, which in the time of Frezier and Feuillee rose only five or six feet out of water. Mr. Caldcleugh, I may add, also shows (and

I received similar accounts) that there has been a considerable decrease in the soundings during the last twelve years in the Bays of Coquimbo, Concepcion, Valparaiso, and Guasco; but as in these cases it is nearly impossible to distinguish between the accumulation of sediment and the upheavement of the bottom, I have not entered into any details.

VALLEY OF COQUIMBO.

(FIGURE 9. EAST AND WEST SECTION THROUGH THE TERRACES AT COQUIMBO, WHERE THEY DEBOUCH FROM THE VALLEY, AND FRONT THE SEA.

Vertical scale 1/10 of inch to 100 feet: horizontal scale much contracted.

Height of terrace in feet from east (high) to west (low):

Terrace F. 364

Terrace E. 302

Terrace D. shown dotted, height not given.

Terrace C. 120

Terrace B. 70

Terrace A. 25 sloping down to level of sea at Town of Coquimbo.)

The narrow coast-plain sends, as before stated, an arm, or more correctly a fringe, on both sides, but chiefly on the southern side, several miles up the valley. These fringes are worn into steps or terraces, which present a most remarkable appearance, and have been compared (though not very correctly) by Captain Basil

Hall, to the parallel roads of Glen Roy in Scotland: their origin has been ably discussed by Mr. Lyell. ("Principles of Geology" 1st edition volume 3 page 131.) The first section which I will give (Figure 9), is not drawn across the valley, but in an east and west line at its mouth, where the step-formed terraces debouch and present their very gently inclined surfaces towards the Pacific.

The bottom plain (A) is about a mile in width, and rises quite insensibly from the beach to a height of twenty-five feet at the foot of the next plain; it is sandy, and abundantly strewed with shells.

Plain or terrace B is of small extent, and is almost concealed by the houses of the town, as is likewise the escarpment of terrace C. On both sides of a ravine, two miles south of the town, there are two little terraces, one above the other, evidently corresponding with B and C; and on them marine remains of the species already enumerated were plentiful. Terrace E is very narrow, but quite distinct and level; a little southward of the town there were traces of a terrace D intermediate between E and C. Terrace F is part of the fringe-like plain, which stretches for the eleven miles along the coast; it is here composed of shingle, and is 100 feet higher than where composed of calcareous matter. This greater height is obviously due to the quantity of shingle, which at some former period has been brought down the great valley of Coquimbo.

Considering the many shells strewed over the terraces A, B, and C, and a few miles southward on the calcareous plain,

which is continuously united with the upper step-like plain F, there cannot, I apprehend, be any doubt, that these six terraces have been formed by the action of the sea; and that their five escarpments mark so many periods of comparative rest in the elevatory movement, during which the sea wore into the land. The elevation between these periods may have been sudden and on AN AVERAGE not more than seventy-two feet each time, or it may have been gradual and insensibly slow. From the shells on the three lower terraces, and on the upper one, and I may add on the three gravel-capped terraces at Conchalee, being all littoral and sub-littoral species, and from the analogical facts given at Valparaiso, and lastly from the evidence of a slow rising lately or still in progress here, it appears to me far more probable that the movement has been slow. The existence of these successive escarpments, or old cliff- lines, is in another respect highly instructive, for they show periods of comparative rest in the elevatory movement, and of denudation, which would never even have been suspected from a close examination of many miles of coast southward of Coquimbo.

(FIGURE 10. NORTH AND SOUTH SECTION ACROSS THE VALLEY OF COQUIMBO.

From north F (high) through E?, D, C, B, A (low), B?, C, D?, E, F (high).

Vertical scale 1/10 of inch to 100 feet: horizontal scale much contracted.

Terraces marked with? do not occur on that side of the valley,

and are introduced only to make the diagram more intelligible. A river and bottom- plain of valley C, E, and F, on the south side of valley, are respectively, 197, 377, and 420 feet above the level of the sea.

AA. The bottom of the valley, believed to be 100 feet above the sea: it is continuously united with the lowest plain A of Figure 9.

B. This terrace higher up the valley expands considerably; seaward it is soon lost, its escarpment being united with that of C: it is not developed at all on the south side of the valley.

C. This terrace, like the last, is considerably expanded higher up the valley. These two terraces apparently correspond with B and C of Figure 9.

D is not well developed in the line of this section; but seaward it expands into a plain: it is not present on the south side of the valley; but it is met with, as stated under the former section, a little south of the town.

E is well developed on the south side, but absent on the north side of the valley: though not continuously united with E of Figure 9, it apparently corresponds with it.

F. This is the surface-plain, and is continuously united with that which stretches like a fringe along the coast. In ascending the valley it gradually becomes narrower, and is at last, at the distance of about ten miles from the sea, reduced to a row of flat-topped patches on the sides of the mountains. None of the lower terraces extend so far up the valley.)

We come now to the terraces on the opposite sides of the east and west valley of Coquimbo: the section in Figure 10 is taken in a north and south line across the valley at a point about three miles from the sea. The valley measured from the edges of the escarpments of the upper plain FF is about a mile in width; but from the bases of the bounding mountains it is from three to four miles wide. The terraces marked with an interrogative do not exist on that side of the valley, but are introduced merely to render the diagram more intelligible.

These five terraces are formed of shingle and sand; three of them, as marked by Captain B. Hall (namely, B, C, and F), are much more conspicuous than the others. From the marine remains copiously strewed at the mouth of the valley on the lower terraces, and southward of the town on the upper one, they are, as before remarked, undoubtedly of marine origin; but within the valley, and this fact well deserves notice, at a distance of from only a mile and a half to three or four miles from the sea, I could not find even a fragment of a shell.

ON THE INCLINATION OF THE TERRACES OF COQUIMBO, AND ON THE UPPER AND BASAL EDGES OF THEIR ESCARPMENTS NOT BEING HORIZONTAL.

The surfaces of these terraces slope in a slight degree, as shown by the sections in Figures 9 and 10 taken conjointly, both towards the centre of the valley, and seawards towards its mouth. This double or diagonal inclination, which is not the

same in the several terraces, is, as we shall immediately see, of simple explanation. There are, however, some other points which at first appear by no means obvious, – namely, first, that each terrace, taken in its whole breadth from the summit-edge of one escarpment to the base of that above it, and followed up the valley, is not horizontal; nor have the several terraces, when followed up the valley, all the same inclination; thus I found the terraces C, E, and F, measured at a point about two miles from the mouth of the valley, stood severally between fifty-six to seventy-seven feet higher than at the mouth. Again, if we look to any one line of cliff or escarpment, neither its summit-edge nor its base is horizontal. On the theory of the terraces having been formed during a slow and equable rise of the land, with as many intervals of rest as there are escarpments, it appears at first very surprising that horizontal lines of some kind should not have been left on the land.

The direction of the diagonal inclination in the different terraces being different, – in some being directed more towards the middle of the valley, in others more towards its mouth, – naturally follows on the view of each terrace, being an accumulation of successive beach-lines round bays, which must have been of different forms and sizes when the land stood at different levels: for if we look to the actual beach of a narrow creek, its slope is directed towards the middle; whereas, in an open bay, or slight concavity on a coast, the slope is towards the mouth, that is, almost directly seaward; hence as a bay alters

in form and size, so will the direction of the inclination of its successive beaches become changed.

(FIGURE 11. DIAGRAM OF A BAY IN A DISTRICT WHICH HAS BEGUN SLOWLY RISING)

If it were possible to trace any one of the many beach-lines, composing each sloping terrace, it would of course be horizontal; but the only lines of demarcation are the summit and basal edges of the escarpments. Now the summit-edge of one of these escarpments marks the furthest line or point to which the sea has cut into a mass of gravel sloping seaward; and as the sea will generally have greater power at the mouth than at the protected head of the bay, so will the escarpment at the mouth be cut deeper into the land, and its summit-edge be higher; consequently it will not be horizontal. With respect to the basal or lower edges of the escarpments, from picturing in one's mind ancient bays ENTIRELY surrounded at successive periods by cliff-formed shores, one's first impression is that they at least necessarily must be horizontal, if the elevation has been horizontal. But here is a fallacy: for after the sea has, during a cessation of the elevation, worn cliffs all round the shores of a bay, when the movement recommences, and especially if it recommences slowly, it might well happen that, at the exposed mouth of the bay, the waves might continue for some time wearing into the land, whilst in the protected and upper parts successive beach-lines might be accumulating in a sloping surface or terrace at the foot of the cliffs which had been lately

reached: hence, supposing the whole line of escarpment to be finally uplifted above the reach of the sea, its basal line or foot near the mouth will run at a lower level than in the upper and protected parts of the bay; consequently this basal line will not be horizontal. And it has already been shown that the summit-edges of each escarpment will generally be higher near the mouth (from the seaward sloping land being there most exposed and cut into) than near the head of the bay; therefore the total height of the escarpments will be greatest near the mouth; and further up the old bay or valley they will on both sides generally thin out and die away: I have observed this thinning out of the successive escarpment at other places besides Coquimbo; and for a long time I was quite unable to understand its meaning. The rude diagram in Figure 11 will perhaps render what I mean more intelligible; it represents a bay in a district which has begun slowly rising. Before the movement commenced, it is supposed that the waves had been enabled to eat into the land and form cliffs, as far up, but with gradually diminishing power, as the points AA: after the movement had commenced and gone on for a little time, the sea is supposed still to have retained the power, at the exposed mouth of the bay, of cutting down and into the land as it slowly emerged; but in the upper parts of the bay it is supposed soon to have lost this power, owing to the more protected situation and to the quantity of detritus brought down by the river; consequently low land was there accumulated. As this low land was formed during a slow elevatory movement, its

surface will gently slope upwards from the beach on all sides. Now, let us imagine the bay, not to make the diagram more complicated, suddenly converted into a valley: the basal line of the cliffs will of course be horizontal, as far as the beach is now seen extending in the diagram; but in the upper part of the valley, this line will be higher, the level of the district having been raised whilst the low land was accumulating at the foot of the inland cliffs. If, instead of the bay in the diagram being suddenly converted into a valley, we suppose with much more probability it to be upraised slowly, then the waves in the upper parts of the bay will continue very gradually to fail to reach the cliffs, which are now in the diagram represented as washed by the sea, and which, consequently, will be left standing higher and higher above its level; whilst at the still exposed mouth, it might well happen that the waves might be enabled to cut deeper and deeper, both down and into the cliffs, as the land slowly rose.

The greater or lesser destroying power of the waves at the mouths of successive bays, comparatively with this same power in their upper and protected parts, will vary as the bays become changed in form and size, and therefore at different levels, at their mouths and heads, more or less of the surfaces between the escarpments (that is, the accumulated beach-lines or terraces) will be left undestroyed: from what has gone before we can see that, according as the elevatory movements after each cessation recommence more or less slowly, according to the amount of detritus delivered by the river at the heads of the successive

bays, and according to the degree of protection afforded by their altered forms, so will a greater or less extent of terrace be accumulated in the upper part, to which there will be no surface at a corresponding level at the mouth: hence we can perceive why no one terrace, taken in its whole breadth and followed up the valley, is horizontal, though each separate beach-line must have been so; and why the inclination of the several terraces, both transversely, and longitudinally up the valley, is not alike.

I have entered into this case in some detail, for I was long perplexed (and others have felt the same difficulty) in understanding how, on the idea of an equable elevation with the sea at intervals eating into the land, it came that neither the terraces nor the upper nor lower edges of the escarpments were horizontal. Along lines of coast, even of great lengths, such as that of Patagonia, if they are nearly uniformly exposed, the corroding power of the waves will be checked and conquered by the elevatory movement, as often as it recommences, at about the same period; and hence the terraces, or accumulated beach-lines, will commence being formed at nearly the same levels: at each succeeding period of rest, they will, also, be eaten into at nearly the same rate, and consequently there will be a much closer coincidence in their levels and inclinations, than in the terraces and escarpments formed round bays with their different parts very differently exposed to the action of the sea. It is only where the waves are enabled, after a long lapse of time, slowly to corrode hard rocks, or to throw up, owing to the supply of

sediment being small and to the surface being steeply inclined, a narrow beach or mound, that we can expect, as at Glen Roy in Scotland ("Philosophical Transactions" 1839 page 39.), a distinct line marking an old sea-level, and which will be strictly horizontal, if the subsequent elevatory movements have been so: for in these cases no discernible effects will be produced, except during the long intervening periods of rest; whereas in the case of step-formed coasts, such as those described in this and the preceding chapter, the terraces themselves are accumulated during the slow elevatory process, the accumulation commencing sooner in protected than in exposed situations, and sooner where there is copious supply of detritus than where there is little; on the other hand, the steps or escarpments are formed during the stationary periods, and are more deeply cut down and into the coast-land in exposed than in protected situations; – the cutting action, moreover, being prolonged in the most exposed parts, both during the beginning and ending, if slow, of the upward movement.

Although in the foregoing discussion I have assumed the elevation to have been horizontal, it may be suspected, from the considerable seaward slope of the terraces, both up the valley of S. Cruz and up that of Coquimbo, that the rising has been greater inland than nearer the coast. There is reason to believe (Mr. Place in the "Quarterly Journal of Science" 1824 volume 17 page 42.), from the effects produced on the water-course of a mill during the earthquake of 1822 in Chile, that the upheaval one mile

inland was nearly double, namely, between five and seven feet, to what it was on the Pacific. We know, also, from the admirable researches of M. Bravais, that in Scandinavia the ancient sea-beaches gently slope from the interior mountain-ranges towards the coast, and that they are not parallel one to the other ("Voyages de la Comm. du Nord" etc. also "Comptes Rendus" October 1842.), showing that the proportional difference in the amount of elevation on the coast and in the interior, varied at different periods.

COQUIMBO TO GUASCO.

In this distance of ninety miles, I found in almost every part marine shells up to a height of apparently from two hundred to three hundred feet. The desert plain near Choros is thus covered; it is bounded by the escarpment of a higher plain, consisting of pale-coloured, earthy, calcareous stone, like that of Coquimbo, with the same recent shells embedded in it. In the valley of Chaneral, a similar bed occurs in which, differently from that of Coquimbo, I observed many shells of the Concholepas: near Guasco the same calcareous bed is likewise met with.

In the valley of Guasco, the step-formed terraces of gravel are displaced in a more striking manner than at any other point. I followed the valley for thirty-seven miles (as reckoned by the inhabitants) from the coast to Ballenar; in nearly the whole of this distance, five grand terraces, running at corresponding heights on both sides of the broad valley, are more conspicuous than the three best-developed ones at Coquimbo. They give to the

landscape the most singular and formal aspect; and when the clouds hung low, hiding the neighbouring mountains, the valley resembled in the most striking manner that of Santa Cruz. The whole thickness of these terraces or plains seems composed of gravel, rather firmly aggregated together, with occasional parting seams of clay: the pebbles on the upper plain are often whitewashed with an aluminous substance, as in Patagonia. Near the coast I observed many sea-shells on the lower plains. At Freyrina (twelve miles up the valley), there are six terraces beside the bottom- surface of the valley: the two lower ones are here only from two hundred to three hundred yards in width, but higher up the valley they expand into plains; the third terrace is generally narrow; the fourth I saw only in one place, but there it was distinct for the length of a mile; the fifth is very broad; the sixth is the summit-plain, which expands inland into a great basin. Not having a barometer with me, I did not ascertain the height of these plains, but they appeared considerably higher than those at Coquimbo. Their width varies much, sometimes being very broad, and sometimes contracting into mere fringes of separate flat-topped projections, and then quite disappearing: at the one spot, where the fourth terrace was visible, the whole six terraces were cut off for a short space by one single bold escarpment. Near Ballenar (thirty-seven miles from the mouth of the river), the valley between the summit-edges of the highest escarpments is several miles in width, and the five terraces on both sides are broadly developed: the highest cannot be less than six hundred

feet above the bed of the river, which itself must, I conceive, be some hundred feet above the sea.

A north and south section across the valley in this part is represented in

Figure 12.

(FIGURE 12. NORTH AND SOUTH SECTION ACROSS THE VALLEY OF GUASCO, AND OF A PLAIN NORTH OF IT.

From left (north, high) to right (south, high) through plains B and A and the River of Guasco at the Town of Ballenar.)

On the northern side of the valley the summit-plain of gravel, A, has two escarpments, one facing the valley, and the other a great basin-like plain, B, which stretches for several leagues northward. This narrow plain, A, with the double escarpment, evidently once formed a spit or promontory of gravel, projecting into and dividing two great bays, and subsequently was worn on both sides into steep cliffs. Whether the several escarpments in this valley were formed during the same stationary periods with those of Coquimbo, I will not pretend to conjecture; but if so the intervening and subsequent elevatory movements must have been here much more energetic, for these plains certainly stand at a much higher level than do those of Coquimbo.

COPIAPO.

From Guasco to Copiapo, I followed the road near the foot of the Cordillera, and therefore saw no upraised remains. At the mouth, however, of the valley of Copiapo there is a plain,

estimated by Meyen ("Reise um die Erde" th. 1 s. 372 et seq.) between fifty and seventy feet in height, of which the upper part consists chiefly of gravel, abounding with recent shells, chiefly of the Concholepas, Venus Dombeyi, and Calyptraea trochiformis. A little inland, on a plain estimated by myself at nearly three hundred feet, the upper stratum was formed of broken shells and sand cemented by white calcareous matter, and abounding with embedded recent shells, of which the Mulinia Byronensis and Pecten purpuratus were the most numerous. The lower plain stretches for some miles southward, and for an unknown distance northward, but not far up the valley; its seaward face, according to Meyen, is worn into caves above the level of the present beach. The valley of Copiapo is much less steeply inclined and less direct in its course than any other valley which I saw in Chile; and its bottom does not generally consist of gravel: there are no step-formed terraces in it, except at one spot near the mouth of the great lateral valley of the Despoblado where there are only two, one above the other: lower down the valley, in one place I observed that the solid rock had been cut into the shape of a beach, and was smoothed over with shingle.

Northward of Copiapo, in latitude 26 degrees S., the old voyager Wafer found immense numbers of sea-shells some miles from the coast. (Burnett's "Collection of Voyages" volume 4 page 193.) At Cobija (latitude 22 degrees 34') M. d'Orbigny observed beds of gravel and broken shells, containing ten species of recent shells; he also found, on projecting points of porphyry, at a

height of 300 feet, shells of Concholepas, Chiton, Calyptraea, Fissurella, and Patella, still attached to the spots on which they had lived. M. d'Orbigny argues from this fact, that the elevation must have been great and sudden ("Voyage, Part Geolog." page 94. M. d'Orbigny (page 98), in summing up, says: "S'il est certain (as he believes) que tous les terrains en pente, compris entre la mer et les montagnes sont l'ancien rivage de la mer, on doit supposer, pour l'ensemble, un exhaussement que ce ne serait pas moindre de deux cent metres; il faudrait supposer encore que ce soulevement n'a point ete graduel;…mais qu'il resulterait d'une seule et meme cause fortuite," etc. Now, on this view, when the sea was forming the beach at the foot of the mountains, many shells of Concholepas, Chiton, Calyptraea, Fissurella, and Patella (which are known to live close to the beach), were attached to rocks at a depth of 300 feet, and at a depth of 600 feet several of these same shells were accumulating in great numbers in horizontal beds. From what I have myself seen in dredging, I believe this to be improbable in the highest degree, if not impossible; and I think everyone who has read Professor E. Forbes's excellent researches on the subject, will without hesitation agree in this conclusion.): to me it appears far more probable that the movement was gradual, with small starts as during the earthquakes of 1822 and 1835, by which whole beds of shells attached to the rocks were lifted above the subsequent reach of the waves. M. d'Orbigny also found rolled pebbles extending up the mountain to a height of at least

six hundred feet. At Iquique (latitude 20 degrees 12' S.), in a great accumulation of sand, at a height estimated between one hundred and fifty and two hundred feet, I observed many large sea-shells which I thought could not have been blown up by the wind to that height. Mr. J.H. Blake has lately described these shells: he states that "inland toward the mountains they form a compact uniform bed, scarcely a trace of the original shells being discernible; but as we approach the shore, the forms become gradually more distinct till we meet with the living shells on the coast." ("Silliman's American Journal of Science" volume 44 page 2.) This interesting observation, showing by the gradual decay of the shells how slowly and gradually the coast must have been uplifted, we shall presently see fully confirmed at Lima. At Arica (latitude 18 degrees 28'), M. d'Orbigny found a great range of sand-dunes, fourteen leagues in length, stretching towards Tacna, including recent shells and bones of Cetacea, and reaching up to a height of 300 feet above the sea. ("Voyage" etc. page 101.) Lieutenant Freyer has given some more precise facts: he states (In a letter to Mr. Lyell "Geological Proceedings" volume 2 page 179.) that the Morro of Arica is about four hundred feet high; it is worn into obscure terraces, on the bare rock of which he found Balini and Milleporae adhering. At the height of between twenty and thirty feet the shells and corals were in a quite fresh state, but at fifty feet they were much abraded; there were, however, traces of organic remains at greater heights. On the road from Tacna to Arequipa, between Loquimbo and

Moquegua, Mr. M. Hamilton found numerous recent sea shells in sand, at a considerable distance from the sea. ("Edinburgh New Philosophical Journal" volume 30 page 155.)

LIMA.

Northward of Arica, I know nothing of the coast for about a space of five degrees of latitude; but near Callao, the port of Lima, there is abundant and very curious evidence of the elevation of the land. The island of San Lorenzo is upwards of one thousand feet high; the basset edges of the strata composing the lower part are worn into three obscure, narrow, sloping steps or ledges, which can be seen only when standing on them: they probably resemble those described by Lieutenant Freyer at Arica. The surface of the lower ledge, which extends from a low cliff overhanging the sea to the foot of the next upper escarpment, is covered by an enormous accumulation of recent shells. (M. Chevalier, in the "Voyage of the 'Bonite'" observed these shells; but his specimens were lost. – "L'Institut" 1838 page 151.) The bed is level, and in some parts more than two feet in thickness; I traced it over a space of one mile in length, and heard of it in other places: the uppermost part is eighty-five feet by the barometer above high-water mark. The shells are packed together, but not stratified: they are mingled with earth and stones, and are generally covered by a few inches of detritus; they rest on a mass of nearly angular fragments of the underlying sandstone, sometimes cemented together by common salt. I collected eighteen species of shells of all ages and sizes.

Several of the univalves had evidently long lain dead at the bottom of the sea, for their INSIDES were incrusted with Balani and Serpulae. All, according to Mr. G.B. Sowerby, are recent species: they consist of: —

1. Mytilus Magellanicus: same as that found at Valparaiso, and there stated to be probably distinct from the true M. Magellanicus of the east coast.
2. Venus costellata, Sowerby "Zoological Proceedings."
3. Pecten purpuratus, Lam.
4. Chama, probably echinulata, Brod.
5. Calyptraea Byronensis, Gray.
6. Calyptraea radians (Trochus, Lam.)
7. Fissurella affinis, Gray.
8. Fissurella biradiata, Trembly.
9. Purpura chocolatta, Duclos.
10. Purpura Peruviana, Gray.
11. Purpura labiata, Gray.
12. Purpura buxea (Murex, Brod.).
13. Concholepas Peruviana.
14. Nassa, related to reticulata.
15. Triton rudis, Brod.
16. Trochus, not yet described, but well-known and very common.

17 and 18. Balanus, two species, both common on the coast.

These upraised shells appear to be nearly in the same proportional numbers-with the exception of the Crepidulae being

more numerous – with those on the existing beach. The state of preservation of the different species differed much; but most of them were much corroded, brittle, and bleached: the upper and lower surfaces of the Concholepas had generally quite scaled off: some of the Trochi and Fissurellae still partially retain their colours. It is remarkable that these shells, taken all together, have fully as ancient an appearance, although the extremely arid climate appears highly favourable for their preservation, as those from 1,300 feet at Valparaiso, and certainly a more ancient appearance than those from five to six hundred feet from Valparaiso and Concepcion; at which places I have seen grass and other vegetables actually growing out of the shells. Many of the univalves here at San Lorenzo were filled with, and united together by, pure salt, probably left by the evaporation of the sea-spray, as the land slowly emerged. (The underlying sandstone contains true layers of salt; so that the salt may possibly have come from the beds in the higher parts of the island; but I think more probably from the sea-spray. It is generally asserted that rain never falls on the coast of Peru; but this is not quite accurate; for, on several days, during our visit, the so-called Peruvian dew fell in sufficient quantity to make the streets muddy, and it would certainly have washed so deliquescent a substance as salt into the soil. I state this because M. d'Orbigny, in discussing an analogous subject, supposes that I had forgotten that it never rains on this whole line of coast. See Ulloa's "Voyage" volume 2 English Translation page 67 for an account of the muddy streets of Lima,

and on the continuance of the mists during the whole winter. Rain, also, falls at rare intervals even in the driest districts, as, for instance, during forty days, in 1726, at Chocope (7 degrees 46'); this rain entirely ruined ("Ulloa" etc. page 18) the mud houses of the inhabitants.) On the highest parts of the ledge, small fragments of the shells were mingled with, and evidently in process of reduction into, a yellowish-white, soft, calcareous powder, tasting strongly of salt, and in some places as fine as prepared medicinal chalk.

FOSSIL-REMAINS OF HUMAN ART.

In the midst of these shells on San Lorenzo, I found light corallines, the horny ovule-cases of Mollusca, roots of seaweed (Mr. Smith of Jordan Hill found pieces of seaweed in an upraised pleistocene deposit in Scotland. See his admirable Paper in the "Edinburgh New Philosophical Journal" volume 25 page 384.), bones of birds, the heads of Indian corn and other vegetable matter, a piece of woven rushes, and another of nearly decayed COTTON string. I extracted these remains by digging a hole, on a level spot; and they had all indisputably been embedded with the shells. I compared the plaited rush, the COTTON string, and Indian corn, at the house of an antiquary, with similar objects, taken from the Huacas or burial-grounds of the ancient Peruvians, and they were undistinguishable; it should be observed that the Peruvians used string only of cotton. The small quantity of sand or gravel with the shells, the absence of large stones, the width and thickness of the bed, and the time requisite for a

ledge to be cut into the sandstone, all show that these remains were not thrown high up by an earthquake-wave: on the other hand, these facts, together with the number of dead shells, and of floating objects, both marine and terrestrial, both natural and human, render it almost certain that they were accumulated on a true beach, since upraised eighty-five feet, and upraised this much since INDIAN MAN INHABITED PERU. The elevation may have been, either by several small sudden starts, or quite gradual; in this latter case the unrolled shells having been thrown up during gales beyond the reach of the waves which afterwards broke on the slowly emerging land. I have made these remarks, chiefly because I was at first surprised at the complete difference in nature, between this broad, smooth, upraised bed of shells, and the present shingle-beach at the foot of the low sandstone-cliffs; but a beach formed, when the sea is cutting into the land, as is shown now to be the case by the low bare sandstone-cliffs, ought not to be compared with a beach accumulated on a gently inclined rocky surface, at a period when the sea (probably owing to the elevatory movement in process) was not able to eat into the land. With respect to the mass of nearly angular, salt-cemented fragments of sandstone, which lie under the shells, and which are so unlike the materials of an ordinary sea-beach; I think it probable after having seen the remarkable effects of the earthquake of 1835 (I have described this in my "Journal of Researches" page 303 2nd edition.), in absolutely shattering as if by gunpowder the SURFACE of the primary rocks near

Concepcion, that a smooth bare surface of stone was left by the sea covered by the shelly mass, and that afterwards when upraised, it was superficially shattered by the severe shocks so often experienced here.

The very low land surrounding the town of Callao, is to the south joined by an obscure escarpment to a higher plain (south of Bella Vista), which stretches along the coast for a length of about eight miles. This plain appears to the eye quite level; but the sea-cliffs show that its height varies (as far as I could estimate) from seventy to one hundred and twenty feet. It is composed of thin, sometimes waving, beds of clay, often of bright red and yellow colours, of layers of impure sand, and in one part with a great stratified mass of granitic pebbles. These beds are capped by a remarkable mass, varying from two to six feet in thickness, of reddish loam or mud, containing many scattered and broken fragments of recent marine shells, sometimes though rarely single large round pebble, more frequently short irregular layers of fine gravel, and very many pieces of red coarse earthenware, which from their curvatures must once have formed parts of large vessels. The earthenware is of Indian manufacture; and I found exactly similar pieces accidentally included within the bricks, of which the neighbouring ancient Peruvian burial-mounds are built. These fragments abounded in such numbers in certain spots, that it appeared as if waggon-loads of earthenware had been smashed to pieces. The broken sea- shells and pottery are strewed both on the surface, and throughout the whole thickness

of this upper loamy mass. I found them wherever I examined the cliffs, for a space of between two and three miles, and for half a mile inland; and there can be little doubt that this same bed extends with a smooth surface several miles further over the entire plain. Besides the little included irregular layers of small pebbles, there are occasionally very obscure traces of stratification.

At one of the highest parts of the cliff, estimated 120 feet above the sea, where a little ravine came down, there were two sections, at right angles to each other, of the floor of a shed or building. In both sections or faces, two rows, one over the other, of large round stones could be distinctly seen; they were packed close together on an artificial layer of sand two inches thick, which had been placed on the natural clay-beds; the round stones were covered by three feet in thickness of the loam with broken sea-shells and pottery. Hence, before this widely spread-out bed of loam was deposited, it is certain that the plain was inhabited; and it is probable, from the broken vessels being so much more abundant in certain spots than in others, and from the underlying clay being fitted for their manufacture, that the kilns stood here.

The smoothness and wide extent of the plain, the bulk of matter deposited, and the obscure traces of stratification seem to indicate that the loam was deposited under water; on the other hand, the presence of sea-shells, their broken state, the pebbles of various sizes, and the artificial floor of round stones, almost prove that it must have originated in a rush of water from the sea

over the land. The height of the plain, namely, 120 feet, renders it improbable that an earthquake-wave, vast as some have here been, could have broken over the surface at its present level; but when the land stood eighty-five feet lower, at the period when the shells were thrown up on the ledge at S. Lorenzo, and when as we know man inhabited this district, such an event might well have occurred; and if we may further suppose, that the plain was at that time converted into a temporary lake, as actually occurred, during the earthquakes of 1713 and 1746, in the case of the low land round Callao owing to its being encircled by a high shingle-beach, all the appearances above described will be perfectly explained. I must add, that at a lower level near the point where the present low land round Callao joins the higher plain, there are appearances of two distinct deposits both apparently formed by debacles: in the upper one, a horse's tooth and a dog's jaw were embedded; so that both must have been formed after the settlement of the Spaniards: according to Acosta, the earthquake-wave of 1586 rose eighty-four feet.

The inhabitants of Callao do not believe, as far as I could ascertain, that any change in level is now in progress. The great fragments of brickwork, which it is asserted can be seen at the bottom of the sea, and which have been adduced as a proof of a late subsidence, are, as I am informed by Mr. Gill, a resident engineer, loose fragments; this is probable, for I found on the beach, and not near the remains of any building, masses of brickwork, three and four feet square, which had been washed

into their present places, and smoothed over with shingle during the earthquake of 1746. The spit of land, on which the ruins of OLD Callao stand, is so extremely low and narrow, that it is improbable in the highest degree that a town should have been founded on it in its present state; and I have lately heard that M. Tschudi has come to the conclusion, from a comparison of old with modern charts, that the coast both south and north of Callao has subsided. (I am indebted for this fact to Dr. E. Dieffenbach. I may add that there is a tradition, that the islands of San Lorenzo and Fronton were once joined, and that the channel between San Lorenzo and the mainland, now above two miles in width, was so narrow that cattle used to swim over.) I have shown that the island of San Lorenzo has been upraised eighty-five feet since the Peruvians inhabited this country; and whatever may have been the amount of recent subsidence, by so much more must the elevation have exceeded the eighty-five feet. In several places in this neighbourhood, marks of sea-action have been observed: Ulloa gives a detailed account of such appearances at a point five leagues northward of Callao: Mr. Cruikshank found near Lima successive lines of sea-cliffs, with rounded blocks at their bases, at a height of 700 feet above the present level of the sea. ("Observaciones sobre el Clima del Lima" par Dr. H. Unanue page 4. – Ulloa's "Voyage" volume 2 English Translation page 97. – For Mr. Cruikshank's observations, see Mr. Lyell's "Principles of Geology" 1st edition volume 3 page 130.) ON THE DECAY OF UPRAISED SEA-SHELLS.

I have stated that many of the shells on the lower inclined ledge or terrace of San Lorenzo are corroded in a peculiar manner, and that they have a much more ancient appearance than the same species at considerably greater heights on the coast of Chile. I have, also, stated that these shells in the upper part of the ledge, at the height of eighty-five feet above the sea, are falling, and in some parts are quite changed into a fine, soft, saline, calcareous powder. The finest part of this powder has been analysed for me, at the request of Sir H. De la Beche, by the kindness of Mr. Trenham Reeks of the Museum of Economic Geology; it consists of carbonate of lime in abundance, of sulphate and muriate of lime, and of muriate and sulphate of soda. The carbonate of lime is obviously derived from the shells; and common salt is so abundant in parts of the bed, that, as before remarked, the univalves are often filled with it. The sulphate of lime may have been derived, as has probably the common salt, from the evaporation of the sea-spray, during the emergence of the land; for sulphate of lime is now copiously deposited from the spray on the shores of Ascension. (See "Volcanic Islands" etc. by the Author.) The other saline bodies may perhaps have been partially thus derived, but chiefly, as I conclude from the following facts, through a different means.

On most parts of the second ledge or old sea-beach, at a height of 170 feet, there is a layer of white powder of variable thickness, as much in some parts as two inches, lying on the angular, salt-cemented fragments of sandstone and under about four inches

of earth, which powder, from its close resemblance in nature to the upper and most decayed parts of the shelly mass, I can hardly doubt originally existed as a bed of shells, now much collapsed and quite disintegrated. I could not discover with the microscope a trace of organic structure in it; but its chemical constituents, according to Mr. Reeks, are the same as in the powder extracted from amongst the decaying shells on the lower ledge, with the marked exception that the carbonate of lime is present in only very small quantity. On the third and highest ledge, I observed some of this powder in a similar position, and likewise occasionally in small patches at considerably greater heights near the summit of the island. At Iquique, where the whole face of the country is covered by a highly saliferous alluvium, and where the climate is extremely dry, we have seen that, according to Mr. Blake, the shells which are perfect near the beach become, in ascending, gradually less and less perfect, until scarcely a trace of their original structure can be discovered. It is known that carbonate of lime and common salt left in a mass together, and slightly moistened, partially decompose each other (I am informed by Dr. Kane, through Mr. Reeks, that a manufactory was established on this principle in France, but failed from the small quantity of carbonate of soda produced. Sprengel "Gardeners' Chronicle" 1845 page 157, states, that salt and carbonate of lime are liable to mutual decomposition in the soil. Sir H. De la Beche informs me, that calcareous rocks washed by the spray of the sea, are often corroded in a peculiar manner;

see also on this latter subject "Gardeners' Chronicle" page 675 1844.): now we have at San Lorenzo and at Iquique, in the shells and salt packed together, and occasionally moistened by the so-called Peruvian dew, the proper elements for this action. We can thus understand the peculiar corroded appearance of the shells on San Lorenzo, and the great decrease of quantity in the carbonate of lime in the powder on the upper ledge. There is, however, a great difficulty on this view, for the resultant salts should be carbonate of soda and muriate of lime; the latter is present, but not the carbonate of soda. Hence I am led to the perhaps unauthorised conjecture (which I shall hereafter have to refer to) that the carbonate of soda, by some unexplained means, becomes converted into a sulphate.

If the above remarks be just, we are led to the very unexpected conclusion, that a dry climate, by leaving the salt from the sea-spray undissolved, is much less favourable to the preservation of upraised shells than a humid climate. However this may be, it is interesting to know the manner in which masses of shells, gradually upraised above the sea-level, decay and finally disappear.

SUMMARY ON THE RECENT ELEVATION OF THE WEST COAST OF SOUTH AMERICA.

We have seen that upraised marine remains occur at intervals, and in some parts almost continuously, from latitude 45 degrees 35' to 12 degrees S., along the shores of the Pacific. This is a distance, in a north and south line, of 2,075 geographical miles.

From Byron's observations, the elevation has no doubt extended sixty miles further south; and from the similarity in the form of the country near Lima, it has probably extended many leagues further north. (I may take this opportunity of stating that in a MS. in the Geological Society by Mr. Weaver, it is stated that beds of oysters and other recent shells are found thirty feet above the level of the sea, in many parts of Tampico, in the Gulf of Mexico.) Along this great line of coast, besides the organic remains, there are in very many parts, marks of erosion, caves, ancient beaches, sand-dunes, and successive terraces of gravel, all above the present level of the sea. From the steepness of the land on this side of the continent, shells have rarely been found at greater distances inland than from two to three leagues; but the marks of sea-action are evident farther from the coast; for instance, in the valley of Guasco, at a distance of between thirty and forty miles. Judging from the upraised shells alone, the elevation in Chiloe has been 350 feet, at Concepcion certainly 625 feet; and by estimation 1,000 feet; at Valparaiso 1,300 feet; at Coquimbo 252 feet; northward of this place, sea-shells have not, I believe, been found above 300 feet; and at Lima they were falling into decay (hastened probably by the salt) at 85 feet. Not only has this amount of elevation taken place within the period of existing Mollusca and Cirripedes; but their proportional numbers in the neighbouring sea have in most cases remained the same. Near Lima, however, a small change in this respect between the living and the upraised was observed: at Coquimbo this was

more evident, all the shells being existing species, but with those embedded in the uppermost calcareous plain not approximating so closely in proportional numbers, as do those that lie loose on its surface at the height of 252 feet, and still less closely than those which are strewed on the lower plains, which latter are identical in proportional numbers with those now cast up on the beach. From this circumstance, and from not finding, upon careful examination, near Coquimbo any shells at a greater height than 252 feet, I believe that the recent elevation there has been much less than at Valparaiso, where it has been 1,300 feet, and I may add, than at Concepcion. This considerable inequality in the amount of elevation at Coquimbo and Valparaiso, places only 200 miles apart, is not improbable, considering, first, the difference in the force and number of the shocks now yearly affecting different parts of this coast; and, secondly, the fact of single areas, such as that of the province of Concepcion, having been uplifted very unequally during the same earthquake. It would, in most cases, be very hazardous to infer an inequality of elevation, from shells being found on the surface or in superficial beds at different heights; for we do not know on what their rate of decay depends; and at Coquimbo one instance out of many has been given, of a promontory, which, from the occurrence of one very small collection of lime-cemented shells, has indisputably been elevated 242 feet, and yet on which, not even a fragment of shell could be found on careful examination between this height and the beach, although many sites appeared very favourable

for the preservation of organic remains: the absence, also, of shells on the gravel-terraces a short distance up the valley of Coquimbo, though abundant on the corresponding terraces at its mouth, should be borne in mind.

There are other epochs, besides that of the existence of recent Mollusca, by which to judge of the changes of level on this coast. At Lima, as we have just seen, the elevation has been at least eighty-five feet, within the Indo-human period; and since the arrival of the Spaniards in 1530, there has apparently been a sinking of the surface. At Valparaiso, in the course of 220 years, the rise must have been less than nineteen feet; but it has been as much as from ten to eleven feet in the seventeen years subsequently to 1817, and of this rise only a part can be attributed to the earthquake of 1822, the remainder having been insensible and apparently still, in 1834, in progress. At Chiloe the elevation has been gradual, and about four feet during four years. At Coquimbo, also, it has been gradual, and in the course of 150 years has amounted to several feet. The sudden small upheavals, accompanied by earthquakes, as in 1822 at Valparaiso, in 1835 at Concepcion, and in 1837 in the Chonos Archipelago, are familiar to most geologists, but the gradual rising of the coast of Chile has been hardly noticed; it is, however, very important, as connecting together these two orders of events.

The rise of Lima, having been eighty-five feet within the period of man, is the more surprising if we refer to the eastern coast of the continent, for at Port S. Julian, in Patagonia, there

is good evidence (as we shall hereafter see) that when the land stood ninety feet lower, the Macrauchenia, a mammiferous beast, was alive; and at Bahia Blanca, when it stood only a few feet lower than it now does, many gigantic quadrupeds ranged over the adjoining country. But the coast of Patagonia is some way distant from the Cordillera, and the movement at Bahia Blanca is perhaps noways connected with this great range, but rather with the tertiary volcanic rocks of Banda Oriental, and therefore the elevation at these places may have been infinitely slower than on the coast of Peru. All such speculations, however, must be vague, for as we know with certainty that the elevation of the whole coast of Patagonia has been interrupted by many and long pauses, who will pretend to say that, in such cases, many and long periods of subsidence may not also have been intercalated?

In many parts of the coast of Chile and Peru there are marks of the action of the sea at successive heights on the land, showing that the elevation has been interrupted by periods of comparative rest in the upward movement, and of denudation in the action of the sea. These are plainest at Chiloe, where, in a height of about five hundred feet, there are three escarpments, – at Coquimbo, where in a height of 364 feet, there are five, – at Guasco, where there are six, of which five may perhaps correspond with those at Coquimbo, but if so, the subsequent and intervening elevatory movements have been here much more energetic, – at Lima, where, in a height of about 250 feet there are three terraces, and others, as it is asserted, at considerably greater heights. The

almost entire absence of ancient marks of sea-action at defined levels along considerable spaces of coast, as near Valparaiso and Concepcion, is highly instructive, for as it is improbable that the elevation at these places alone should have been continuous, we must attribute the absence of such marks to the nature and form of the coast-rocks. Seeing over how many hundred miles of the coast of Patagonia, and on how many places on the shores of the Pacific, the elevatory process has been interrupted by periods of comparative rest, we may conclude, conjointly with the evidence drawn from other quarters of the world, that the elevation of the land is generally an intermittent action. From the quantity of matter removed in the formation of the escarpments, especially of those of Patagonia, it appears that the periods of rest in the movement, and of denudation of the land, have generally been very long. In Patagonia, we have seen that the elevation has been equable, and the periods of denudation synchronous over very wide spaces of coast; on the shores of the Pacific, owing to the terraces chiefly occurring in the valleys, we have not equal means of judging on this point; and the very different heights of the upraised shells at Coquimbo, Valparaiso, and Concepcion seem directly opposed to such a conclusion.

Whether on this side of the continent the elevation, between the periods of comparative rest when the escarpments were formed, has been by small sudden starts, such as those accompanying recent earthquakes, or, as is most probable, by such starts conjointly with a gradual upward movement, or by

great and sudden upheavals, I have no direct evidence. But as on the eastern coast, I was led to think, from the analogy of the last hundred feet of elevation in La Plata, and from the nearly equal size of the pebbles over the entire width of the terraces, and from the upraised shells being all littoral species, that the elevation had been gradual; so do I on this western coast, from the analogy of the movements now in progress, and from the vast numbers of shells now living exclusively on or close to the beach, which are strewed over the whole surface of the land up to very considerable heights, conclude, that the movement here also has been slow and gradual, aided probably by small occasional starts. We know at least that at Coquimbo, where five escarpments occur in a height of 364 feet, the successive elevations, if they have been sudden, cannot have been very great. It has, I think, been shown that the occasional preservation of shells, unrolled and unbroken, is not improbable even during a quite gradual rising of the land; and their preservation, if the movement has been aided by small starts, is quite conformable with what actually takes place during recent earthquakes.

Judging from the present action of the sea, along the shores of the Pacific, on the deposits of its own accumulation, the present time seems in most places to be one of comparative rest in the elevatory movement, and of denudation of the land. Undoubtedly this is the case along the whole great length of Patagonia. At Chiloe, however, we have seen that a narrow sloping fringe, covered with vegetation, separates the present sea-beach from

a line of low cliffs, which the waves lately reached; here, then, the land is gaining in breadth and height, and the present period is not one of rest in the elevation and of contingent denudation; but if the rising be not prolonged at a quick rate, there is every probability that the sea will soon regain its former horizontal limits. I observed similar low sloping fringes on several parts of the coast, both northward of Valparaiso and near Coquimbo; but at this latter place, from the change in form which the coast has undergone since the old escarpments were worn, it may be doubted whether the sea, acting for any length of time at its present level, would eat into the land; for it now rather tends to throw up great masses of sand. It is from facts such as these that I have generally used the term COMPARATIVE rest, as applied to the elevation of the land; the rest or cessation in the movement being comparative both with what has preceded it and followed it, and with the sea's power of corrosion at each spot and at each level. Near Lima, the cliff-formed shores of San Lorenzo, and on the mainland south of Callao, show that the sea is gaining on the land; and as we have here some evidence that its surface has lately subsided or is still sinking, the periods of comparative rest in the elevation and of contingent denudation, may probably in many cases include periods of subsidence. It is only, as was shown in detail when discussing the terraces of Coquimbo, when the sea with difficulty and after a long lapse of time has either corroded a narrow ledge into solid rock, or has heaped up on a steep surface a NARROW mound of detritus, that we can confidently

assert that the land at that level and at that period long remained absolutely stationary. In the case of terraces formed of gravel or sand, although the elevation may have been strictly horizontal, it may well happen that no one level beach-line may be traceable, and that neither the terraces themselves nor the summit nor basal edges of their escarpments may be horizontal.

Finally, comparing the extent of the elevated area, as deduced from the upraised recent organic remains, on the two sides of the continent, we have seen that on the Atlantic, shells have been found at intervals from Eastern Tierra del Fuego for 1,180 miles northward, and on the Pacific for a space of 2,075 miles. For a length of 775 miles, they occur in the same latitudes on both sides of the continent. Without taking this circumstance into consideration, it is probable from the reasons assigned in the last chapter, that the entire breadth of the continent in Central Patagonia has been uplifted in mass; but from other reasons there given, it would be hazardous to extend this conclusion to La Plata. From the continent being narrow in the southern-most parts of Patagonia, and from the shells found at the Inner Narrows of the Strait of Magellan, and likewise far up the valley of the Santa Cruz, it is probable that the southern part of the western coast, which was not visited by me, has been elevated within the period of recent Mollusca: if so, the shores of the Pacific have been continuously, recently, and in a geological sense synchronously upraised, from Lima for a length of 2,480 nautical miles southward, – a distance equal to that from the Red

Sea to the North Cape of Scandinavia!

CHAPTER III. ON THE PLAINS AND VALLEYS OF CHILE: – SALIFEROUS SUPERFICIAL DEPOSITS

Basin-like plains of Chile; their drainage, their marine origin.

Marks of sea-action on the eastern flanks of the Cordillera.

Sloping terrace-like fringes of stratified shingle within the valleys of the Cordillera; their marine origin.

Boulders in the valley of Cachapual.

Horizontal elevation of the Cordillera.

Formation of valleys.

Boulders moved by earthquake-waves.

Saline superficial deposits.

Bed of nitrate of soda at Iquique.

Saline incrustations.

Salt-lakes of La Plata and Patagonia; purity of the salt; its origin.

The space between the Cordillera and the coast of Chile is on a rude average from eighty to above one hundred miles in width; it is formed, either of an almost continuous mass of mountains, or more commonly of several nearly parallel ranges, separated by plains; in the more southern parts of this province

the mountains are quite subordinate to the plains; in the northern part the mountains predominate.

Конец ознакомительного фрагмента.